ECODESIGN IMPLEMENTATION

A Systematic Guidance on Integrating Environmental Considerations into Product Development

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Springer

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ECODESIGN Implementation

A Systematic Guidance on Integrating Environmental Considerations into Product Development

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PREFACE

Environmentally sound product design, in short ECODESIGN, is at the same time a key success factor for industry as well as a necessity. Low material and energy input over the entire life cycle of a product and an optimized environmental performance is of central importance to fulfill recent and future requirements. Innovative solutions, which are characterized by a better life cycle performance, should be the result of a systematic ECODESIGN process. The basis of a successful ECODESIGN process is a comprehensive analysis of the given situation. It's of central importance to understand a specific situation from an environmental viewpoint for developing specific improvement strategies and measures.

The ECODESIGN PILOT provides a methodology to define successful improvement strategies and measures in a multidisciplinary working team. This methodology was already published by Kluwer Academic Publishers (Wimmer, W., Züst, R.: "ECODESIGN-Pilot – Product-Investigation- Learning- and Optimisation-Tool", Kluwer Academic Publishers, Amsterdam, 2002.). The online version is available on: www.ecodesign.at/pilot. Both methods, the book with the CD-ROM and the web page, have been recognized as helpful tools in the area of ECODESIGN.

Wolfgang Wimmer from the Vienna University of Technology (TU Wien), Rainer Züst from the Swiss Federal Institute of Technology (ETH Zürich), and Kun-Mo Lee from the Ajou University (Korea), have used the ECODESIGN PILOT in projects with industry in Europe and Asia in the last three years. In addition interested experts and students from different universities have been trained in using this methodology. The experiences have clearly shown that the PILOT is a good instrument to define specific improvement measures. But the ECODESIGN PILOT has to be integrated in an overall product improvement process.

This book provides a systematic integration of significant environmental aspects and stakeholder requirements as well as the environmental communication of the ECODESIGN results.

We would like to thank all those who have supported us in writing this book. We are especially indebted to the Alliance for Global Sustainability for their support in publishing the book. We also thank our colleagues from industry and academia for the interesting discussion and ideas to improve the ECODESIGN process. Last but not least, we want to express our deep gratitude to friends and families for their encouragement and understanding, especially in the final phase of this book project.

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June 2004

INTRODUCTION

The systematic improvement of the environmental performance of industrial products and services is no longer a sophisticated issue or luxury. Environmentally oriented solutions are core elements of good governance and good business. An integrated approach for that is necessary. And that would mean that the environmental dimension has to be an integral part of all planning and decision-making processes within a company.

Environmentally sound product design, short ECODESIGN, has a great potential to improve the environmental performance of a product while extending the customers benefit as well as improving the economic performance. That's one of the most important reasons why industry should be more and more interested in effective methods and tools for implementing ECODESIGN.

Most important when improving a current situation is to initiate a culture of innovative thinking, and to encourage product designers and project managers finding new and more attractive solutions. This implies that designers should have the knowledge and ability to apply methods and tools in a multidisciplinary working team by integrating relevant stakeholder requirements, considering global, regional and local mechanisms, as well as doing a systematic and broad analysis of a given situation to achieve a better environmental performance of their products.

It is of central importance for the industry to produce excellent products and to provide best services. All products and services have to be improved continually in an innovative way. That is the basis of successful business. And one key issue in this context is certainly anticipating trends. Followings are several significant trends from an environmental view:

- Customers and society are increasingly expecting products and services that are environmentally optimized. They would like to have more than a face-lifting. They are really interested in innovative solutions. These improvements are communicated by an increasing number of companies with eco-labels or other easy to understand information.
- The number of laws and directives related to environmental issues are increasing continually. It is important to realize the new requirements from relevant regulations (e.g. new environmental directives in the electronic sector).
- Competitors are offering more and more products with specific environmental benefits. They communicate these products and services through environmentally oriented labels or with the information that the customers and the society will have certain benefits.

- The ecological environment is still “suffering”. The impacts through the enormous energy and material flows are still increasing. It’s obvious for many people that our industrialized life style is influencing and damaging the environment. Specific environmental problems are reported frequently in newspapers. One example is the CO_2-emission and the connected global warming phenomenon.

These environmental trends should be considered as an opportunity rather than a threat. Environmental issues should be accepted as driving forces to rethink and redesign the own products, services and activities in an innovative way. Quite a number of innovative enterprises have already realized this challenge.

It might be of great benefit for the industry to provide customers with environmentally sound products and services. The question normally asked is how to realize a better product design from an environmental point of view. In the last few years different approaches have been developed. Methods, which support the product design process with specific strategies and measures, are of high interest. One of these approaches is the ECODESIGN PILOT (Wimmer and Züst 2002).

The ECODESIGN Product-Investigation-, Learning- and Optimization-Tool (PILOT) provides strategies and measures in a structured and well-documented way. Therefore, working with the ECODESIGN PILOT starts with the information about the most relevant product life cycle stage regarding the significant environmental aspects. Then possible strategies are pointed out to the design team, which has to discuss these strategies in a first step; afterwards possible measures are identified using checklists.

Practical experiences have shown that the ECODESIGN PILOT offers the design team a framework for better and successful products. From an integrated view, ECODESIGN implementation addresses the whole process of considering and integrating environmental aspects and stakeholder requirements in product design and development as well as environmental communication of environmental improvements to the market. These steps and processes, as well as the additional required methods, will be provided within this book. Figure 1 depicts the road-map throughout the whole book.

The product design team has to take into consideration environmental aspects as well as stakeholder requirements. Defining design task is one thing and improving a real product and communicating the improvement to the market is another. There is a need for more guidance to improve and to communicate the realized ECODESIGN improvements in an appropriate way.

Industry and especially the experts in the design departments have to answer the following five questions, related to Figure 1:

1. Product Modeling: How to proceed to get an adequate model and description of a product (system), which can be used in the ECODESIGN process?
2. Life Cycle Assessment: How to evaluate significant environmental aspects of a product throughout its entire life cycle?
3. ECODESIGN Tasks: How to derive successful design tasks out of environmental aspects and stakeholder requirements?
4. Product Improvement: How to develop a better product? How to proceed with the ECODESIGN tasks in the product development process?
5. Environmental Communication: How to communicate the environmental improvements of a product in an effective way?

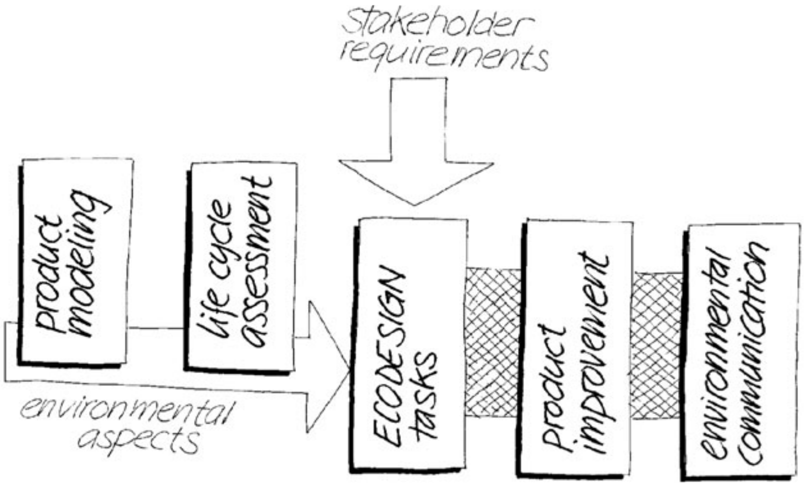


Figure 1 Road-map of the book with main chapters for implementing ECODESIGN.

These are five central questions in the process of implementing ECODESIGN. These questions should be treated carefully. The goal of the book is to answer these main questions by providing corresponding tools, methods and guidelines, as well as giving specific advises for a successful ECODESIGN process.

The practical application of ECODESIGN has shown that the systematic and broad life cycle thinking process at the beginning is of central importance. The whole product, that would mean all stages, from the use of raw materials, manufacture, distribution, product use to its end of life, has to be analyzed, described and evaluated from an environmental point of view.

The environmental evaluation might be achieved with Life Cycle Assessment (LCA). The theory and practice of LCA is described in the second chapter. A full LCA study in general is time and cost intensive, and for these reasons often not feasible for the design team on a regular basis. Therefore other ways to identify significant environmental aspects as well as easy to use Internet based tools and methods are described in the book. Especially the ECODESIGN PILOT's Assistant helps to make a short time environmental evaluation (see section 3.5).

For the practical implementation of ECODESIGN this book provides a total of twelve steps meant for improving a reference product. These steps span from the description of a product with environmental parameters to the assessment of significant environmental aspects as well as integration of stakeholder requirements for deriving ECODESIGN improvement options to the generation of an improved product concept to continue the integration of ECODESIGN during product development. Table 1 lists these twelve recommended steps for implementing ECODESIGN in practice together with leading questions, task description and the referring sections of the book.

Table 1 Twelve steps for implementing ECODESIGN in practice.

Step	*Leading questions*	*Tasks*	*Section*
1	What product is to be redesigned?	Describing the reference product with environmental parameters.	1.4
2	What are the stakeholder requirements? What is expected from the product?	Performing Environmental Quality Function Deployment.	3.3
3	What are the strengths and weaknesses compared with competitor products?	Environmental Benchmarking with the competitor's products.	3.4
4	What are the significant environmental aspects of the reference product throughout its entire life cycle?	Applying the ECODESIGN PILOT's Assistant or performing Life Cycle Assessment and interpretation of results.	3.5 or 2.3, 3.6
5	How to combine stakeholder requirements and significant environmental aspects into improvement strategies?	Deriving common ECODESIGN improvement strategies.	3.7.1
6	Which ECODESIGN guidelines should be implemented in the product?	Applying ECODESIGN PILOT's checklists to determine redesign tasks.	3.7.2 3.7.3
7	What are the environmental product specifications to start with?	Starting product improvement.	4.2
8	How to modify the functional structure of the product?	Adding new functions to and/or modifying functions of the reference product.	4.3
9	How to generate new ideas for the functions of the product?	Performing creativity session and/or searching for patents.	4.4
10	How to generate and select the best product concept variants?	Assembling ideas corresponding to each function of the redesigned product concepts and evaluate them against criteria.	4.5
11	How does the improved product look like?	Continuing embodiment design and layout, prototyping and testing.	4.6
12	How to communicate the environmental improvements of the product to the market?	Performing Environmental Product Declaration or self-declared environmental claims.	5.2

The twelve steps will be explained throughout the book with a real product example. The example chosen is a water kettle for boiling water. The water kettle is an easily understandable household appliance, containing mainly plastic and steel and using electricity to heat the water. There are also important stakeholder requirements that should be integrated into the design process (e.g. the new EU directives for the

electronic sector). With this product example implementing ECODESIGN a systematic guidance on integrating environmental considerations into product development will be demonstrated. Throughout the book an improved water kettle will be developed (Figure 2).

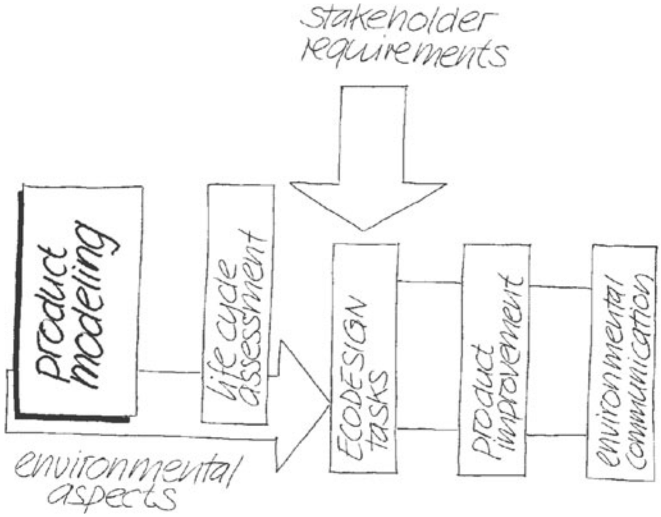
Figure 2 Improved water kettle.

The target audiences for this book are designers, project managers and environmental experts in companies as well as students from environmental science and engineering design who are involved in design projects.

Each part of the book might be used alone, depending on the individual background or the specific goals of the reader.

Chapter 1

PRODUCT MODELING



Industry has to initiate and to implement successful ECODESIGN processes to improve their products. One of the first questions might be: Which are the most significant environmental aspects of a product? If the design team doesn't have a broad understanding of the product and the product's life cycle stages it can't answer this question. The design team needs an adequate description of the product system and especially a good understanding about the influence of people who might be involved or affected by the product over its entire life cycle. A product system comprises of the product itself and all information, material and energy needed throughout its entire life cycle stages.

Therefore, the ECODESIGN process starts with a systematic description of the product system which has to be improved. The central question is: How to proceed to get a good understanding about the product system? The purpose of the modeling process is to anticipate the problem from different viewpoints and to pass on information especially to the later Life Cycle Assessment.

The modeling process is divided into three steps:

- It starts with general principles of thinking and acting. Especially heuristic principles as well as the influence of different people, in the sense of a socio-technical system, will be discussed.
- The second step leads to a qualitative description. A central aspect will be a discussion of the environmental parameters, which describe the product system in an environmentally oriented way.
- The goal of the third step is to derive a quantitative model, based on environmental parameters. The environmental parameter as well as the quantitative product model will be used for later steps in the book.

1.1 Introduction

Let's start with the following situation. Assume you have new mobility needs. A future job forces you to travel more. Unfortunately the public transportation system doesn't fulfill the new requirements. There is a need of a car for driving about 20 000 km per year. You found in the newspaper two alternatives: A new car with an efficient motor and a used car for a low price. Both alternatives fulfill in general your requirements. But which alternative would be cheaper over the next five years? In order to compare the two alternatives you probably use cost parameter like investment, fuel cost, etc. A possible result of such a comparison is listed in Table 2.

Table 2 Evaluation of two alternatives with cost parameters.

Parameter	*Alternative A*	*Alternative B*
General information		
Car type	Car type A, new, with a small and efficient motor	Care type B, five years old, low investment
Weight	1450 kg	1750 kg
Functionality	5 seats, ABS	7 seats, 4 wheel drive
General cost		
Investment	25 000 €	12 000 €
Cost for product use		
Driving distance per year	20 000 km/year	20 000 km/year
Liter gasoline/100 km	6 L/100 km	10 L/100 km
Gasoline consumption over 5 years	6000 liter	10 000 liter
Fuel and oil cost (over 5 years)	6000 €	10 000 €
Insurance (over 5 years)	6000 €	8000 €
Tax (over 5 years)	5000 €	6000 €
Repair (over 5 years)	2000 €	8000 €
Cost concerning end of life		
Value after 5 years	12 000 €	2000 €
Total costs over 5 years	32 000 €	42 000 €
Costs per 1 km	0.32 €/km	0.42 €/km

The calculation in Table 2 includes cost information over five years occurring to the user. The whole investigation is based on a simple cost model using cost parameter without considering any external influences or other use scenarios. It might be that other assumptions will change the result. Following are examples given:

- repair and service cycles might be different,
- the energy consumption itself depends on the way of driving,
- the price per liter gasoline might be different especially over a longer period,
- the value of the car after five years depends on the future preference for color and car type, and
- accidents or non-foreseen defects might increase the costs during the use of the car.

Environmentally oriented impacts and emerging costs caused by environmental impacts are not taken into account. Similar to the given car example using cost parameters it will be demonstrated in this chapter how to do develop environmental parameters as a basis for an environmental assessment of products.

Industry has to provide innovative products and services with excellent performance for the customers. One aspect, which demonstrates the product's excellence, is related to material and energy consumption over the entire product life cycle. Critical and informed customer will not accept any more material and energy intensive products. It might be caused for example by unacceptable environmental impacts, especially during the use of the product.

In practice there is a need for a deep and systematic understanding of the planning situation. Otherwise the information basis will be too weak for the following assessment and improvement processes. Therefore there are typical questions: Which product has to be improved? What are the functions of the product? What has happened over the entire product life stages? Who might be affected? What is the behavior of the users? What are the influences on the environment? These questions have to be answered at the beginning of the product modeling process.

The modeling process is divided into three general elements (see Figure 3):

- *General principles*: The focus will be first on heuristic principles as preconditions of a systematic systems analysis. A set of general principles supports the whole process of modeling and especially the environmentally oriented analysis and description task.
- *Qualitative description*: The product system has to be analyzed under different environmentally oriented aspects. The goal of the second element is to provide a set of environmental parameters, which support the collection of relevant environmentally oriented information for later assessment and design tasks.
- *Quantitative modeling*: The content of the third step is the process of collecting quantitative information. A quantitative description of the product will be developed to determine significant environmental aspects of the product.

These three elements of the product modeling process, as shown in Figure 3, will be explained in the following sections.

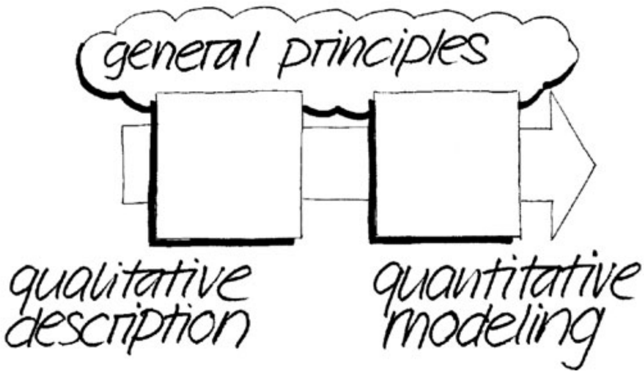


Figure 3 Process for product modeling.

1.2 General principles

There is a lot of interaction between the product and the environment over the entire product life cycle. Different interactions might influence the products performance and the effects on the environment. Therefore the product should be analyzed in a broader context. In a broad and systematic investigation it's important to take into consideration other aspects and especially alternative influences and behavior of the user of the product system. In this case it's essential to adapt especially the heuristic principles "considering time-related changes", "thinking in alternatives" and "working from an overall to a detailed view" as well as a systems-oriented way of modeling considering significant impacts and relevant influences from the product to its environment.

Some basic remarks about systems thinking and a short discussion about the main heuristic principles will be described in the following sections.

1.2.1 Systems Thinking

Systems Thinking is the holistically oriented and context related way of thinking. The process of defining and describing the product in a systems-oriented way can essentially be simplified through the analysis of possible impacts through which the individual influences on the product can be determined. The extent of the influences over the time and their eventual consequences can be further investigated both internally and externally (Figure 4).

The following questions might support the process of finding relevant influence factors, related to the environmental considerations:

- Which are the most significant influences by laws, standards and society?
- Which are the relevant influences by customers? Who is using the product? What are the people's behaviors? Who might be affected by the product?
- Which are the significant influences by the enterprise itself? How can the corporate politics and strategy influence the product design?

- Which are the major influences on the environment caused by the product system throughout its entire life cycle? How can these impacts influence the product design?

Figure 4 Example of influence analysis for products, distinguishing internal and external influence factors (Züst and Schregenberger, 2003).

The product water kettle will be used as an example to demonstrate and to develop the concept throughout the book. Ideas about Systems Thinking will be illustrated with the example of the water kettle. The water kettle provides e.g. boiling water for tea, coffee or soups.

Different aspects influence the design of the water kettle. Following are some influences which are related to an environmental perspective:

- Laws (legal compliance): two current directives in the EU, namely "Waste Electrical and Electronic Equipment" (WEEE, 2003) and "Restrictions on the use of certain Hazardous Substances" (RoHS, 2003).
- Customers are expecting high-energy efficiency of the water kettle.
- Suppliers' environmental performance concerning the state of the art of the available material and production technologies.
- Corporate politics and strategies, especially environmental policy and strategy based on the corporate environmental management system according to ISO 14001 (ISO 14001, 1996).
- Financial resources, e.g. budget for the ECODESIGN project, based on the corporate budget.

If a system includes affected, involved and thus interacting people, we call it a socio-technical system. Socio-technical systems have some specific characteristics:

- the response of certain system elements on distinct events may be delayed,
- the behavior of certain elements could be non-linear and non-stable, and
- the system behavior cannot be judged intuitively because individual human behavior is hardly predictable and often contra intuitive.

1.2.2 Heuristic principles

Basic beliefs and principles, short heuristic principles, suggest how the planning and development team should proceed within a problem-solving process. In the context of the product modeling task the following three heuristic principles are of great importance (Züst, 2004):

- Considering time-related changes.
- Thinking in alternatives/thinking in options.
- Working from an overall to a detailed view.

Considering time-related changes

Products, their system and the environment are changing constantly over time. Consequently, product modeling requires a systematic view to future development and trends (Figure 5). That is why the design team must constantly deal with new situations. There are two aspects to consider:

- Anticipation of future changes and their integration into the modeling process based, for example, on stakeholder analysis.
- Evaluation of previously developed models against new relevant knowledge, and adaptation to the product model, if necessary.

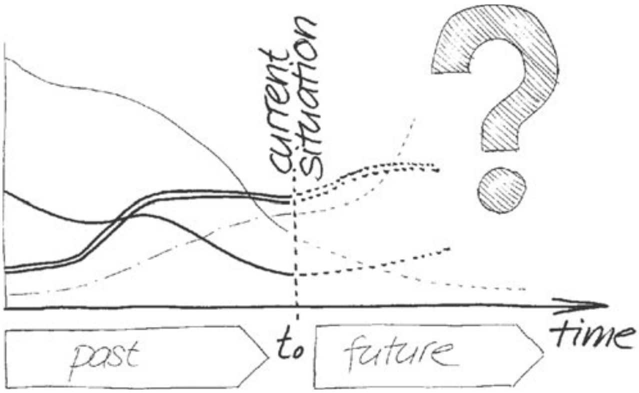


Figure 5 Considering information from the past and present as well as future trends (Züst, 2004)

Typical trends are increasing world population, globalization of the market (higher mobility of people and goods), environmental problems (e.g. global warming), and globalization of life-styles (increasing potential of envy). Some of the trends are related to environmental issues.

Prognoses about internal system behavior as well as the environment are not trivial, especially if different people are involved and/or affected by the product itself. Generally, neither extrapolations nor growth models suffice on their own. The behavior of the actual product, as well as its interaction and links with the user and its environment, must be fundamentally analyzed and assessed before improving them.

Following is an example about the application of the heuristic principle "Considering time-related changes" based on the water kettle. The described trends might be relevant in the improvement process of the water kettle:

- More restrictive environmental laws and standards can be expected, e.g. limitation of emissions (manufacturing processes, technology use), restriction of waste (manufacture and product use), avoiding hazardous substances (manufacture), increasing product efficiency (technology used) and required recyclability of the product (end of life scenarios).
- Demographic distribution of people in industrialized countries, e.g. higher demand for water kettle.
- New life-styles, e.g. increasing consumption of instant food as well as higher consumption of (healthy) tea and soups require hot water within short time and therefore the use of a water kettle.

Thinking in alternatives/thinking in options

The goal of product modeling is comprehensively considering all relevant aspects of a product at the beginning of the modeling process. Thinking in alternatives and options as well as using scenarios to examine alternatives play a central role in analyzing problems and developing solutions.

There are always a lot of different options and alternatives. It's only the question how to find them. New ideas arise often at the border to other disciplines. One solution might be in combining various people with different background and expertise. New aspects and other ideas might be generated in a process of creativity. The goal of a multidisciplinary working team is to combine different opinions, to integrate views from different major areas, and to develop a common understanding of a given situation (Figure 6).

Figure 6 Integration of different aspects (Luttropp and Züst, 1998).

The following questions might support the process of finding other ideas and alternatives:

- Are there other influences on the product system?
- What are the other future changes? Which trends might influence the product design?

- Are there other people who might be involved or affected by the product? Do you know other possibilities to use the product?
- Are there other impacts on the environment caused by the product over its entire life cycle?

Working from an overall to a detailed view

A further element of successful planning is effectively structuring working levels. Systems should be structured hierarchically and specified with an increasing degree of detail (Figure 7).

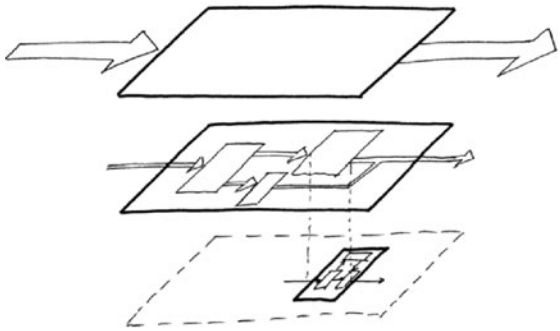


Figure 7 Hierarchically structured system (Züst, 2004).

The application of the heuristic principle “working from an overall to a detailed view” promotes

- the focus on relevant aspects of the product system,
- the development of an optimal solution through a stepwise procedure, and
- the limitation of the planning expenses.

The heuristic principle “working from an overall to a detailed view” supports the design team by analyzing and understanding a given situation.

Following is an example of the application of the heuristic principle “working from an overall to a detailed view” based on the water kettle. At the beginning of the design process the project manager would like to have a first estimation about possible environmental impacts. He performs a calculation based on the scenario that the water kettle will be used frequently in an office. A first overview shows the following picture:

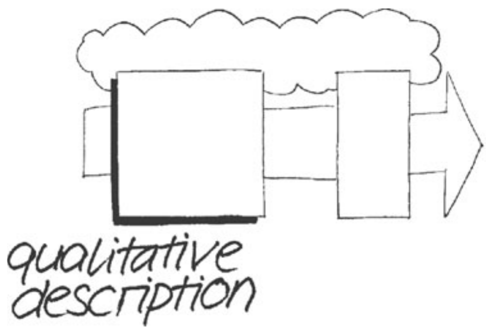
- Material consumption: 870 g (about 500 g plastic, 200 g cardboard, 120 g stainless steel, about 50 g copper).
- Use scenario: estimated product lifetime is three years, a frequent use implies three uses per day over 250 days per year. This equals 750 uses per year and over three years in total 2250 uses can be expected; one use equals boiling of ½ liter of water.

The project manager recognizes that more then 1 cubic meter of water will be boiled with this water kettle, based on the chosen use scenario. A significant consumption of resources – and probably also a relevant impact on the environment – might occur

during the product use stage. This is a first hypothesis. This information is also important to focus the future work of analyzing and evaluating towards the right direction.

Systems Thinking and the heuristic principles are guiding the product modeling process. These should be used in combination with the whole modeling process to ensure a broad and comprehensive view, which is the basis for developing an adequate product model.

1.3 Qualitative description



The planning team should have a clear description of all product life cycle stages and interactions with the environment to make the ECODESIGN process efficient. An adequate life cycle model supports the process of gathering quantified information over the entire product life cycle and provides the base for a systematic environmentally oriented evaluation. The result of the ECODESIGN process depends on the quality of the life cycle model. The product modeling process starts with the qualitative description of the product system.

Common design parameters, e.g. esthetic, quality and ergonomic are already part of the design process. Designers have a lot of experience to handle all these parameters. But often the environmental dimension is missing. To fill that gap so called "environmental parameters" will be developed throughout the following sections.

1.3.1 General description of the product

First of all it is important to gain an overview of a current planning situation and to describe the planning situation in general at the beginning of the study. Especially in between the project managers, respectively the design team and those who initiated the product improvement or development process of a product, a common understanding of the planning situation has to be developed.

Table 3 shows the description of a product in general, especially on technical and, sometimes also on major economic information related to the environment. The goal of the general description is to have a first idea about the product to be improved.

Table 3 Set of general environmental parameters.

General environmental parameters	
Name of the product	Identification of the product, eventual with picture or diagram
Weight	Total weight of the product including packaging
Volume	Total spatial requirements of the product
Supply part's environmental performance	Overall environmental performance of parts and components purchased from suppliers
Lifetime	Planned years of operation
Functionality	Description of all functions and quality of function fulfillment of the product

Some additional information about the business case, planned maintenance and current sales per year might be useful to understand the product in a broader sense. Table 4 shows the additional information.

Table 4 Set of additional information.

Additional information	
Business case	Information about the mix of products and services associated with the product (e.g. offered maintenance, possibility to repair)
Current sales per year	Number of products sold in one year

The information collected in Tables 3 and 4 will be used later for the quantified product model.

1.3.2 Life cycle model

For an effective ECODESIGN process all product life cycle stages have to be analyzed and looked at for possible effects on the environment. In the context of ECODESIGN we describe the life cycles as a process of resource transformation with the following stages:

- Use of raw materials: extracting resources (material and energy) from nature and production of raw and ancillary materials from the extracted resources.
- Manufacture: manufacture of parts, sub-assemblies and components, software and others. This stage requires adequate tool machines, production equipment, operating material and energy, manufacturing related infrastructure and transportation systems.
- Distribution: transportation to the location where the product will be used.
- Product use: the customers use the product, additional energy and operating material may accrue, and emissions, effluents and waste might be generated. Maintenance and service are needed as well as measures to upgrade the product or to prolong the useful life of a product.
- End of life: the obsolete product has to be disposed of, reused, recycled or incinerated.

Following is a qualitative description of the life cycle model for the water kettle example.

- Use of raw materials: production of PP, PA and PVC granule, production of steel and copper, production of cardboard.
- Manufacture: different manufacturing processes, e.g. injection molding (for housing, lid and switch unit).
- Distribution: distribution within Europe, done by 40-ton trucks.
- Product use: boiling of water.
- End of life: disposal via municipal waste (mixture of recycling, landfill and waste incineration depending on the country).

Normally product life cycle stages are not arranged in a linear way. Between and within every product life cycle stage other cycles may occur. Four examples are described by Wimmer and Züst, 2002:

- repair, service and maintenance cycle in the product use stage,
- recycling processes (manufacture once again or once more and product use once again and once more),
- reverse manufacturing by disassembling, testing and assembling again, and
- upgrading to prolong the product lifetime by adding or replacing functionality.

Within the product modeling process the focus will be also on ancillary processes which are necessary to manufacture, transport, use and dispose of the product. The design team might influence the need for ancillary processes in the design process. In this case these elements are also part of the product system that has to be redesigned.

1.3.3 Environmental parameters

A systematic evaluation of the significant environmental aspects of a product requires quantitative information structured in a systematic way and covering the entire life cycle stages. Therefore, life cycle related environmental parameters are described in Table 5. With these environmental parameters all the information needed for a life cycle model can be collected.

The list of the environmental parameters, shown in Table 5, represents a general framework which supports the design team in collecting all relevant environmentally oriented information. This list of environmental parameters is general but might be extended for specific products.

Table 5 Set of environmental parameters related to the product life cycle.

Environmental parameter	*Explanation*
Use of raw materials	
Materials used	Basic materials used in the product
Problematic materials	Materials which might cause serious environmental problems (even in small quantities)
Manufacture	
Production technology	Main manufacturing processes and technologies
Production waste	Waste generated in the production processes
Distribution	
Packaging	Amount of packaging materials and kind of packaging
Transportation	Mode of transport and distance traveled to deliver the product
Product use	
Usability	Performance of use referring to the functions of the product and intended use of the product
Energy consumption	Energy used, e.g. kWh for the intended use of the product
Waste (generated)	Waste generated during the use of the product
Noise and vibrations	Expressing disturbance during the product use
Emissions	Release of environmentally harmful substance during product use
Maintenance	Simplicity for maintaining the product
Reparability	Simplicity for repairing the product
End of life	
Fasteners and joints	Number and kind of fasteners
Time for disassembly	Time required for dismantling the product
Rate of reusability	Parts meant for reuse expressed in percentage of the total weight of the product
Rate of recyclability	Materials meant for recycling expressed in percentage of the total weight of the product

1.3.4 People's involvement

A product model is normally based on a scenario. Different assumptions have to be made for the use of raw materials, manufacture, distribution, product use and end of life, especially if the design team is planning a new product. These uncertainties have to be analyzed and all possible deviations have to be evaluated carefully. That's the goal of the following planning step.

In general, a product model includes affected, involved and thus interacting people. In this case the product is no longer a purely technical system that has to be analyzed and changed. In a broader perspective we have a socio-technical system with significant interaction – links and cycles (feed-backs) – between the product and the product life cycle stages as well as people who are involved or affected by the product system.

Therefore it is necessary to investigate other scenarios such as inefficiency. From practical experience the following are some of the typical examples of inefficiency:

- Manufacture: the manufacturing process control doesn't work on a high level. People are not motivated to improve the production and assembly processes. The failure rate is high, the enterprise is loosing a lot of money, and the environmental impacts are increasing due to waste.
- Distribution: the packaging is of high volume and weight. The product density per transport unit is low, packaging is cost intensive.
- Product use: once the product is sold the manufacturer has no more influence over the product itself. It's up to the new owner to use the product in an efficient way. If there is a lack of information or motivation to improve the way of using this product, people's behavior probably will not be very efficient.
- End of life: the product is rather small and fits in a waste bag. It might be that people will discard the obsolete product in the waste stream and inhibit that way a systematic recycling and reuse of the product.

The user might also use the product in a wrong way probably due to missing instruction or wrong design of the product itself. An example could be a home-worker drilling machine. When using too large drills, the motor might be damaged due to overload.

In some cases there is also a danger of manipulation. The new owner will exchange, up-grade or simply repair the product in a way which is obviously not foreseen.

This short discussion shows that there are a lot of possibilities for inefficient or wrong use as well as manipulation in the product use stage. Manipulations might be prevented by other business cases, for example "product service systems". A product service system can be defined as the result of an innovation strategy, shifting the business focus from designing and selling products only, to selling a system of products and services which are jointly capable of fulfilling specific customers demands (UNEP, 2002).

The goal of the planning task is to find, apart from a regular scenario, especially inefficient, wrong product use and manipulation. Following is a description about those scenarios for a water kettle.

The water kettle can be used in different ways. People using the water kettle might re-boil already hot water because they don't realize that the water remaining in the kettle is still on high temperature. Re-boiling would mean higher energy consumption. Similar problem could be the fact that some people put too much water in the kettle. In this case the energy consumption would be much higher than needed. The example shows two additional realistic scenarios:

- Some users re-boil water every time without controlling the temperature of the water remaining in the kettle.
- Some users put too much water in the kettle without controlling how much they actually need.

Both cases are causing an inefficient use of the product. The planning team has to discuss these additional scenarios. If the scenarios are relevant, those will be part of the product modeling and need to be considered in the product improvement process.

1.3.5 Possible accidents and defects

The planning team also has to think about unexpected situations that might cause other negative impacts on the environment. Accidents and defects, which occur suddenly, normally without any indication in advance, are such elements of the product modeling process. A typical example is a broken piece or module caused by a mechanical or thermal overload during the product use stage. These defects might cause other implications or accidents. In the design phase it's not trivial to recognize and evaluate this cause and effect chain.

Some situations might be problematic from the point of accidents and defects. One example is the use of toxic substances in a cooling system. The coolant has to be handled very carefully in manufacture and during the end of life stage. If there is a leakage occurring during manufacture, distribution, product use or end of life stage, the coolant is discharged into the environment and causes damages.

Regarding the water kettle such possible accidents could result if users forget to put water into the kettle. The heating module might be damaged by overheating or the housing starts melting. Other scenarios could be a broken cable or a leakage in the housing caused by mechanical impact. Measures have to be taken to avoid anything, which could cause additional environmental impact or result in disposal of the product.

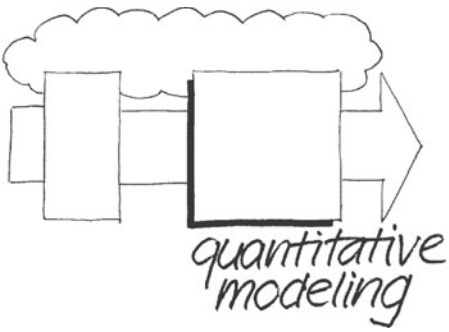
Following is the description about possible accidents and defects that might cause additional environmental impacts based on the water kettle:

- Customers are using too less water. The housing of the water kettle might be overheated. This scenario is not feasible because there is an automatically switch-off function even for heating without water (this is a required safety feature).
- A broken cable or a broken housing caused by improper use could lead to an early disposal, such an accident is not realistic.
- There are no toxic substances in and around the kettle that might be discharged into the environment.

The example shows no more relevant scenarios caused by accidents or defects.

The result of the first modeling task is a qualitative description of the product over the entire life cycle of a product based on a standard scenario. That would mean that the model is based on specific assumptions, e.g. the way how the product will be used. In some product cases the life cycle model will be different. Other realistic scenarios have to be analyzed, especially if people can influence the product's performance. There is a need for defining these additional scenarios to have a broader understanding of a given planning situation.

1.4 Quantitative modeling



The main question of the following modeling task is: Which are the quantified input and output factors in every product life cycle stage based on the standard scenario as well as on the additional scenarios? The goal of the quantitative modeling task is to gather quantified information systematically.

The quantitative modeling task starts first with a structured set of environmental parameters that supports the planning team in collecting quantitative information. The bases for the quantitative modeling task are the:

- general description from Table 3,
- additional information from Table 4,
- set of environmental parameters related to the product life cycle from Table 5,
- set of realistic scenarios for inefficiency, wrong product use and manipulation, and
- set of realistic scenarios caused by accidents and defects.

All results from the previous modeling task should be compiled in a single list. This list now contains a quantitative description of the product, all product life cycle stages and realistic scenarios.

Table 6 shows a complete collection of relevant environmentally oriented information for the water kettle. At the end of the list there is information about other scenarios, which might be relevant for the following product improvement process as well as additional information.

Table 6 Environmental parameters with quantified information including other realistic scenarios and additional information of the water kettle.

Environmental parameters – general information	
Name of the product	Water kettle
Weight	Weight 0.87 kg (including packaging)
Volume	200 × 200 × 350 mm
Supply part's environmental performance	Heater and cable
Lifetime	3 years
Functionality	Heating and boiling water with automatic switch off
Environmental parameters – life cycle related information	
Use of raw material	
Materials used	410 g PP, 120 g steel, 20 g PA, 72 g PVC, 48 g Cu, 200 g cardboard
Problematic materials	PVC in cables
Manufacture	
Production technology	Injection molding (housing: 330 g PP; lid: 80 g PP; switch unit: 20 g PA) Cutting and bending (120 g steel) Extrusion (72 g PVC) Stranded cable (48 g Cu) Cutting and gluing of box (200 g cardboard)
Production waste	None
Distribution	
Packaging	Single use cardboard box
Transportation	3000 km by 40 ton truck
Product use	
Usability	No flexibility in moving the kettle due to fixed cable
Energy consumption	Boiling 0.5 liter water requires 0.0545 kWh, for 2250 uses this equals 122.6 kWh
Waste (generated)	None
Noise and vibrations	None
Emissions	None
Maintenance	To clean the water kettle especially from calcium deposit (descaling)
Reparability	Not possible
End of life	
Fasteners and joints	Snap fit and screws
Time for disassembly	Disassembly is not possible
Rate of reusability	Reuse of parts is not possible
Rate of recyclability	50% of the total weight of the product
Information about other realistic scenarios	
Re-boil (product use)	The energy consumption per use can be about 20% higher: this can occur with a probability of about 50%

(Continued)

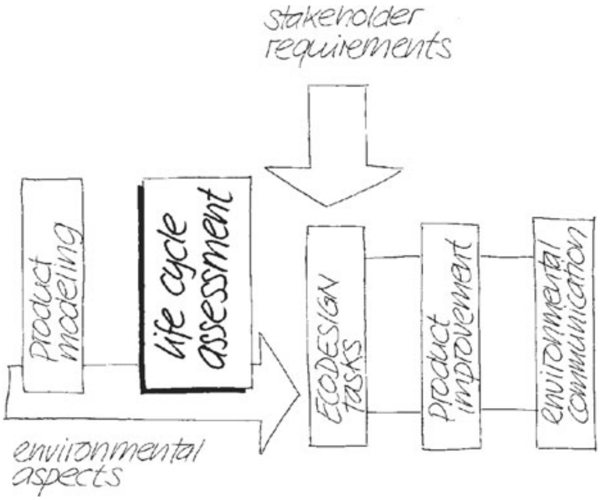
Table 6 (Continued)

Warm-up too much water (product use)	The energy consumption per use can be about 100% higher: this can occur with a probability of about 25%
Additional information	
Business case	Selling water kettles on the European market; no additional service and maintenance is provided
Current sales per year	91 800 (reference year is 2003)

The results from Table 6 will be used later in Life Cycle Assessment in chapter 2 and for deriving ECODESIGN tasks in chapter 3. There the concept of the environmental parameters will be used to translate stakeholder requirements into ECODESIGN improvement strategies.

Chapter 2

LIFE CYCLE ASSESSMENT



Life Cycle Assessment (LCA) is an important tool for the implementation of the ECODESIGN. In this chapter, the environmental aspects of a product are assessed using LCA. An LCA is based on entire life cycle stages of a product spanning from the use of raw materials to the end of life stage. The product for LCA was defined in chapter 1, product modeling.

Topics covered in chapter 2 include:

- Concept of LCA through an example of fuel combustion;
- General principles of LCA;
- Mandatory elements of an LCA: goal and scope definition with special emphasis on setting the product system boundary, inventory analysis, impact assessment, and key issues identification; and
- Optional elements of an LCA together with the techniques to check the quality of the LCA results.

Step by step procedure for the implementation of LCA using the water kettle was applied to aid the understanding of the procedure. Special attention was paid to practical application of the LCA method aimed at ECODESIGN and environmental communication of the product.

2.1 Introduction to Life Cycle Assessment (LCA)

Products generate emissions and consume resources throughout their entire life cycle stages. This indicates that environmental impacts occur throughout the entire life cycle of a product. Since the types of emissions can be diverse, such as emissions to air, water and land, and since there can be numerous types of resources used, there can be many different types of environmental impacts.

We call the effect on the environment as environmental impact. The consumption of resources and emissions of pollutants to the environment cause impact on the environment. There are different types of environmental impacts depending on the nature of the resources consumed and pollutants emitted.

What matters most, however, is the type of the impact and its intensity on the environment. If we, as a society, perceive a certain environmental impact serious, then the impact must be reduced. This requires the identification of the emissions and resources with respect to its nature, quantity, and most importantly where they come from. The outcome of the identification process is the environmental key issue(s) or weak point(s) of a product.

If we can pin-point the emissions and resources of concern and quantify relative contribution of each of them to the total impact caused by the product, then we will be able to find solutions to deal with them, either by reducing the use of the problematic materials or by adopting less problematic product functional features. This process involves redesign of a product, and we call it ECODESIGN process where environmental aspects are integrated into product design and development.

LCA is an analytical tool that quantifies the consumption of energies and materials and the emissions to air, water and land occurring throughout the entire life cycle of a product. Furthermore, LCA assesses environmental impacts resulting from these consumptions and emissions. In the international standardization community LCA was standardized as international standards, ISO (International Organization for Standardization) 14040 series.

Most product designers and developers are not familiar with the analysis of the environmental impacts of a product. Our experience shows that sometimes they may not possess the basic understanding of the environmental impacts of a product such that it is difficult to answer the question what is the environment and what are the typical impacts on the environment. In this sense, understanding the basics of the environmental impact should come first before discussing the environmental assessment of a product.

Most well-known environmental impact would be global warming where global temperature increases as a result of increased emission of CO_2. Other well-known impact may be acidification where acid rain acidifies soils and lakes resulting from the emission of SO_x.

To foster good understanding about the cause and effect relationship, from resource consumption and pollutants emissions to the environmental impacts, LCA will be discussed first by addressing a simple question, burning of fuel. Then touching on different types of environmental impacts in the context of LCA will be made. The question is: What would be the environmental impact of burning one liter of fuel (gasoline) for driving a car? You may think this is an easy question to answer. Is it really easy? We intend to explain the LCA concept by addressing this question.

The first answer you may think of is that the burning will result in emission of air pollutants. They are carbon dioxide (CO_2), NO_x, SO_x, unburned hydrocarbon, particulate matters such as black soot, and carbon monoxide (CO). Of course, the burning will lead to depletion of the crude oil reserve. The emitted air pollutants will cause various environmental problems. For instance, CO_2 causes global warming, NO_x and SO_x lead to acid rain, NO_x enriches nutrient level in the soil, lake and sea, unburned hydrocarbon and CO cause smog, particulate matter causes respiratory ailment to humans, among others.

Indeed, the environmental impact from the combustion of one liter of fuel is diverse and can be damaging. However, there are untold stories behind the burning of the fuel. You only think about the burning of the fuel itself. But where do you think the fuel originates from?

Here, we have to address the entire life cycle as described in chapter 1. Clearly crude oil in nature is the starting point for the fuel. The crude oil must be extracted from the underground. The extracted crude oil must then be transported to a place for consumption by an oil tanker. The oil tanker needs fuel (diesel) to sail. The transported crude oil undergoes refinery operation to generate various petroleum products including fuels such as gasoline, diesel, and heavy oil, etc. Only then fuel is produced as a product. Before you can use it, however, the fuel must be delivered to the user. Now you have fuel to burn. In the case of fuel, there is no disposal, for the use (burning) will leave nothing behind to dispose of. However, for most durable products, once they are used, they are discarded at the end of their useful life, and then they are disposed of.

The extraction, transport, and refinery of the crude oil also require energies and materials, and generate emissions to air, water and land. In addition, delivery of the fuel requires energy. And the crude oil reserve in nature decreases because of the fuel production and consumption. If you did not consider these in your first answer, then it is because you only focused on the final product you are dealing with, not considering the origin of the product.

From the above discussion you will see that product (fuel, gasoline) is only one part of the entire chain or network associated with the product. In LCA we call this chain or network a product system. As discussed in chapter 1, this means that no product exists alone. It must have materials, components and parts to become a product and require energy for transport, manufacturing and operation.

The product system consists of distinctive stages called life cycle stages. The life cycle stages of a product include use of raw materials, manufacture, distribution, product use and end of life. In the case of fuel example, extraction and transport corresponds to the use of raw materials stage, refinery to the manufacture stage, delivery to the distribution stage and burning to the product use stage. There is no end of life stage in the case of fuel.

You will understand by now that burning one liter of fuel not only generates emissions during its use stage, but also consumes energies and materials and depletes resources during the other life cycle stages. Thus the environmental impacts from the burning of one liter of fuel occur throughout the entire life cycle of the fuel, not just from the combustion itself. In the case of fuel, therefore, LCA can be used to quantify resources consumption and environmental emissions, and assess their environmental impacts resulting from the burning of one liter of fuel throughout its entire life cycle stages.

This view is the holistic thinking or life cycle thinking of the environmental impacts of a product, and is vital to the recognition of the environmental impacts associated with the product. Obviously, the environmental impacts based on the life cycle thinking are the right answer to the question raised here.

Below is a brief description of environmental impacts in terms of cause and effect on the environment. Environmental impacts chosen here for description are those commonly considered in LCA. There are six different typical environmental impacts: they include global warming, ozone layer depletion, acidification, eutrophication, photochemical oxidant creation, and abiotic resource depletion.

- Global warming is a rise in temperature in the atmosphere due to greenhouse gases such as CO_2 and methane. The greenhouse gases in the atmosphere trap heat reflected from the earth surface to the space. The heat trapped in the atmosphere results in increase in temperature in the atmosphere. This leads to the change in climate that causes severe drought, extreme torrential rain, change in vegetation and aquatic life and flooding of low lands. International effort such as the Kyoto protocol is being ratified by many nations to abate the global warming problem.
- Ozone layer depletion is a decrease in ozone concentration in the stratosphere due to breakdown of ozone by the chlorinated compounds such as CFC 11 (commonly known Freon, a refrigerant). Thinning ozone layer in the stratosphere results in free passage of harmful radiations through the atmosphere such as ultraviolet rays that cause skin cancer and mutation of plants. Since the implementation of the international treaty banning the use of the ozone depleting substances, the ozone layer depletion problem appears to be under control.
- Acidification is an increase in proton or hydrogen ion concentration in water due to acidifying gases such as NO_x and SO_x. Acid rain is the most common carrier causing acidification. Fish kills in lakes, dying trees in forests, and corrosion of old buildings are the results of acidification.
- Eutrophication is an increase in nutrient (nitrogen and phosphorus) concentration in lakes or sea such that excessive growth of aquatic organisms called algae result. The excessive growth of algae imparts obnoxious taste to water and causes red tide in the sea. The red tide is the leading cause of the kills of aquaculture and other aquatic life.
- Photochemical oxidant creation is an increase in ground level ozone concentration causing the commonly known phenomenon called smog. Substances such as hydrocarbon from automobiles' exhaust gases are major contributors to the smog formation. The smog causes harm to the human's respiratory tract and retards the growth of plants.
- Abiotic resource depletion refers to the consumption of non-renewable resources such as crude oil, iron ore, bauxite, etc. Depletion of the non-renewable resources will lead to the transformation of the human society into different life style, relying on different resources to sustain human society. Unless there are alternatives to the current non-renewable resources, such as alternative fuels to crude oil, the human society cannot sustain its current living standard or life style.

The information of the environmental impacts given above is essential in assessing the impact from the product on the environment. In other words, resources consumption and emissions to the environment from the product must be linked to relevant types of environmental impacts, and the linking process can only be made based on the information given above about the nature of the environmental impacts.

2.2 General principles of LCA

LCA is a tool that enables to analyze complicated product system systematically. The systematic approach includes dividing the LCA procedure into four distinct phases. They are: Goal and scope definition, Life cycle inventory analysis, Life cycle impact assessment, and Life cycle interpretation (ISO 14040, 1997). Figure 8 shows four phases of LCA. Below is a brief description of each LCA phase.

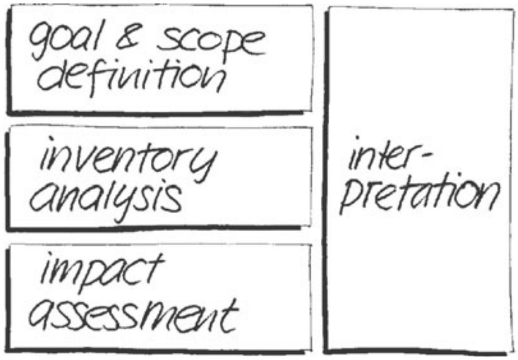


Figure 8 Four phases of LCA.

Goal and scope definition phase

The goal definition deals with questions like "why perform LCA, who are the target audiences, and what is the application of the LCA results". The scope definition is much more complicated than the goal definition. Questions to address in the scope definition include defining product system and setting its boundary, defining product function and its unit, and setting data quality requirements and data parameters, among others.

A product system is a new concept to most designers and product developers, for they only focus on product itself. In fact, they deal with components, parts, and materials for their product design and development activities. All these are essential constituents of the product system, though they don't represent the entire product system.

A product system consists of elements called unit processes and activities associated with the product from use of raw materials to end of life. There can be numerous processes in a product system. However, only seemingly significant ones, such as major components and materials, are included because of practical reasons.

Furthermore, one of the major objectives in performing LCA is to identify key processes and activities that cause serious environmental impacts. Thus a decision rule to exclude less important processes and activities has often been applied.

Figure 9 shows an example of a product system for fuel (gasoline) that we cited for illustrative purpose in section 2.1. Note that Figure 9 is for illustrative purpose as such it depicts a simplified version of the true product system of fuel.

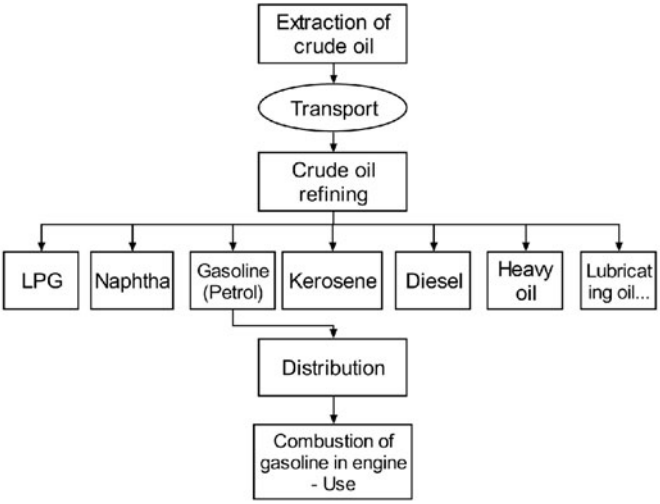


Figure 9 Product system of the fuel (gasoline).

Life cycle inventory analysis phase

Once the goal and scope definition phase is completed, a product system for subsequent data collection and analysis of the data phase begins. It is a phase requiring intensive data collection. Data are collected for each unit process and activity. Input into the process and activity (raw and ancillary materials and energy) and output from the process and activity (products, co-products, and emissions to air, water and land) are quantified.

Emissions to air, water and land are pollutants generated in a product system and discharged into the environment. Discharge into the river or sea falls under the emissions to water, into atmosphere falls under the emissions to air, and into the soil under the emissions to land. The resources consumed include raw and ancillary materials used in the manufacturing and use of the product. Those consumed for the generation of energy, fuel and electricity also counted as resources consumed.

All the emissions generated and resources consumed are called inventory parameters. The collection and analysis of the quantified data for the inventory parameters is called inventory analysis. The inventory analysis results therefore list

inventory parameters with their values. This can be considered environmental profile of the product. Table 7 lists an example of commonly known inventory parameters with categories to which they belong.

Table 7 Examples of data category and parameter.

Category	*Parameter*
Emissions to air	CO_2, CH_4
Emissions to water	Phenol, Phosphate, Nitrate
Emissions to land	Solid waste
Resources	Iron ore, Crude oil

After summing up all the data from all the unit processes and activities in the product system based on its contribution to the product, the life cycle inventory result of the product is obtained. The life cycle inventory results list the inventory parameters with its value throughout its entire life cycle.

Inventory analysis of the fuel was conducted and the result is shown in Table 8. The table lists inventory parameters and their values in each life cycle stage of the fuel.

Table 8 says that in order to produce 1 kg of fuel (gasoline), 1.173 kg of crude oil was consumed while emitting 2693.7 g CO_2, 4.81 g CH_4 (methane), and 4.51 g NO_x. The table also lists crude oil consumption as well as emissions of CO_2, methane, and NO_x per life cycle stage. From Table 8 you can overview the entire profile of the environmental aspects of a product system throughout its entire life cycle. One may call Table 8 the environmental profile of the fuel (gasoline).

Table 8 Example of inventory analysis results of 1 kg fuel (unit: g/kg fuel).

Inventory parameter	*Use of raw materials*	*Manufacture*	*Distribution*	*Product use*	*Total*
Crude oil	1173.00	0.00	0.00	0.00	1173.00
CO_2	336.72	449.28	27.20	1880.50	2693.70
CH_4	4.69	0.07	0.05	0.00	4.81
NO_x	1.74	0.97	0.25	1.55	4.51

Life cycle impact assessment phase

Once you quantify inventory parameters, you will ask what those numbers in the life cycle inventory analysis table mean to the environmental impact. The environmental impacts resulting from the inventory parameters are now assessed in the life cycle impact assessment phase. According to ISO 14040 series, this phase consists of mandatory elements (classification and characterization) and optional elements (normalization and weighting).

In classification, the inventory parameters are classified into or linked to several types of impact or commonly called impact categories. Typical impact categories of the impact assessment include abiotic resource depletion (ARD), global warming (GW), ozone layer depletion (OD), photochemical oxidant creation (POC), acidification (AD),

and eutrophication (EU). Basic information about the six well-defined impact categories was presented in section 2.1.

Based on the understanding of the impacts on the environment in different impact categories described in section 2.1, you need to link or connect inventory parameters to the corresponding impact categories. Some inventory parameter affects more than one impact categories such as NO_x, while others affect only one impact category. Table 9 is an example of the linking between inventory parameters and impact categories for the fuel example.

Table 9 Example of classification of the fuel: linking between inventory parameter and impact category.

Inventory parameter	*Impact category*
CO_2	GW
CH_4	GW, POC
NO_x	AD, EU, POC
Crude oil	ARD

Once classification is completed, impact caused by each inventory parameter in a given impact category is quantified. This quantification of impact is termed characterization of the impact or simply characterization. The characterization requires a factor for each inventory parameter that indicates the degree of contribution by the inventory parameter to the impact category in a relative term. This factor is called characterization or equivalency factor.

A characterization factor is based on the equivalency principle. Let's take an example of two green house gases, CO_2 and CH_4 (methane). It is known that 1 g of methane contributes to global warming 23 times greater than 1 g of CO_2. Thus it can be restated that 1 g methane is equivalent to 23 g CO_2 in terms of contribution to the global warming. This is the equivalency principle. The factor 23 is the characterization factor for methane, while the factor for CO_2 is 1. In atmospheric science, global warming contributed by 1 g CO_2 is defined as unit global warming potential (GWP). Thus the GWP of methane is 23 g CO_2 equivalent.

Total impact of a product on a given impact category can be obtained by multiplying the quantity of each inventory parameter by its characterization factor and summing them up. This is called characterized impact. Table 10 shows the characterized impact of the fuel in the case of global warming.

Table 10 is different from Table 8 because the latter simply lists the quantity of resources consumed and emissions generated, while the former assesses the impact

Table 10 Characterized impact of the fuel (for global warming impact category).

Inventory parameter	*Load (g/kg fuel)*	*Factor (g CO_2 eq/g)*	*Characterized impact (g CO_2 eq/kg fuel)*
CO_2	2693.70	1	2693.70
CH_4	4.81	23	110.63
Total			2804.33

on the environment caused by resources and emissions. Often people consider inventory values are sufficient enough in assessing the environmental impact of a product. However, you will see that impact assessment gives different perspective to the environmental impact of the product.

In Table 8, CO_2 was 560 times greater in quantity than methane. However, Table 10 shows that contribution by CO_2 to the global warming impact is only 24 times greater than that of methane. What matters most is the impact on the environment, not the quantity of the inventory parameters. Compared to the environmental profile represented by the inventory analysis results in Table 8, the impact assessment results in Table 10 more realistically reflect the environmental profile of the product.

When there is a need to express environmental impact of a product in a single value, you need to proceed further to calculate normalized and weighted impact of the product. Normalization is a process dividing the characterized impact of a product by the characterized impact of a chosen geographical area for one year. The normalized impact thus represents the degree of relative impact caused by the product to the total impact of the geographical region where the product belonged. Weighting means the assignment of weight or relative significance to the impact categories based on social, ethical, and political values. Thus weighted impact represents the impact of the product reflecting the societal value.

Life cycle interpretation phase

Life cycle interpretation is the last phase in LCA. Here environmentally significant processes, materials and activities or so-called key issues are identified. The key issues are one of the most important results of the LCA study and they become starting points for environmental improvement of a product by identifying weak points of the product to be redesigned.

The key issues are identified using the characterized impact. Normally the characterized impacts are available in matrix form. The matrix consists of rows and columns where the rows include inventory parameters and the columns unit processes and activities. For a given impact category, divide all the cells of the matrix by the total characterized impact and calculate the percent value of each cell. The percent value is the relative contribution of each cell to the total characterized impact. By applying an arbitrary criterion such as 1%, one can identify cells of which relative contribution exceeds this criterion. The identified cells have corresponding inventory parameter and unit process or activity. Thus key issues consisting of inventory parameter and unit process or activity are known.

Table 11 shows the life cycle interpretation results (key issue identification) of the fuel in the case of global warming. CO_2 is the dominant source of the impact, and the product use stage (67%) is the most dominant life cycle stage followed by the manufacture (16%) and use of raw materials stage (16%). In Table 11, you can detect key inventory parameters and unit processes or activities. The key inventory parameter is CO_2, and key activities are the product use stage and the manufacture and the use of raw materials stage. Key issues can also be identified from the other impact categories such as acidification, abiotic resource depletion, etc.

Table 11 Life cycle interpretation results (key issue identification) of the fuel (for global warming impact category) (unit: g CO_2 eq/fu).

Inventory parameter	*Use of raw materials*	*Manufacture*	*Distribution*	*Product use*	*Total*
CO_2	336.72	449.28	27.20	1880.50	2693.70
CH_4	107.87	1.61	1.15	0.00	110.63
Total	444.59	450.89	28.35	1880.50	2804.33
	16%	16%	1%	67%	100%

Key issues based on the entire impact categories of the product system can also be identified using the weighted impact results. As shown in Figure 10, the most significant sources of impact caused by the fuel are abiotic resource depletion (ARD) during the use of raw materials stage (77%) followed by global warming (GW) in the product use stage (17%).

The result shown in Figure 10 is the weighted impact result of the product (fuel) by considering impacts from all the impact categories and relative significance or weight of each impact category. On the other hand, the result in Table 11 is based on the characterized impact of a single impact category, and no weight of the impact category is involved in identifying the key issues. Thus the key issues identified under the weighted impact (Figure 10) case are different from those under the characterized impact (Table 11) case.

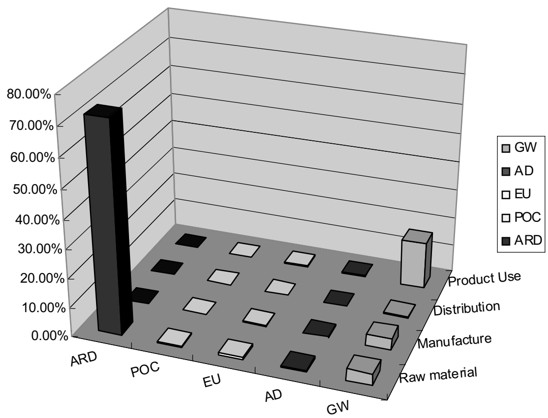


Figure 10 Key issues identified for the fuel based on weighted impact.

In addition to the key issue identification, the life cycle interpretation phase includes various checking and evaluating measures that assess the LCA results with respect to completeness, sensitivity and consistency. For further details, proceed to section 2.4.

Additional remarks

Once a product with improved environmental performance is produced through the redesign of the reference product, the improved environmental aspects of the newly redesigned product must be communicated to the market. This may increase consumer's awareness of the product such that market share may increase or the image of the company may be enhanced. These are the most likely incentives for a company to design and develop products with improved environmental performance. For this reason, environmental communication to the consumers, in particular, in the form of Environmental Product Declaration (EPD) (ISO/TR 14025, 2000) of a product is an essential element of the eco-product development. This is one of the major reasons for performing environmental assessment of a product, in particular, using LCA.

Implementing LCA for the environmental assessment of a product has drawbacks. It takes too much time and too much cost to perform. In the light of fast changing product field, a quick and easy to use tool for the environmental assessment is a must in product design and development. As such a simplified version of LCA has been on the horizon mainly from the industry side.

Simplification can be achieved by reducing the complexity of a product system during the scope definition phase. There are two commonly used approaches: One is the approach that reduces the effort required for data collection by using similar data, omitting certain life cycle stages, and exclusion of particular inventory parameters. The other approach mainly focuses only on particular types of environmental impacts or inventory parameters such as CO_2. For instance, CO_2 LCA is quite common in Japan.

The following sections present the LCA method in two different perspectives. One is detailed LCA dealing with mandatory elements defined in the ISO 14040 standard (ISO, 1997) and the other optional elements in the same document. Finally, summary section presents key points of this chapter. The water kettle example was thus used in this chapter to illustrate practical implementation of LCA.

2.3 Life Cycle Assessment in detail

An LCA is a robust tool as such it is quite complicated in nature and takes much time and effort to implement it. However, the implementation of LCA applied to ECODESIGN and environmental communication, in particular Environmental Product Declaration (EPD), should not take much time and effort. This section on LCA in detail will guide you to the implementation of LCA quickly and efficiently, while achieving the goal of identifying key environmental issues and generating information for the environmental aspects of a product.

The real question is how to identify or pin-point the source of problematic emissions and resources throughout the entire life cycle of a product. Since a product is a collection of many parts, components, different types of materials, manufacturing processes, different product use and end of life stages, the identification is not an easy task.

In accordance with ISO 14040 (ISO, 1997), mandatory elements of an LCA are discussed here. The LCA topics discussed in this section only focused on essential elements for the generation of the key issues and environmental profile of a product. Other mandatory elements are needed to ensure high credibility of the LCA results; however, in all practical purposes, the LCA method given in this section will be sufficient for the identification of key issues and generation of an environmental profile of a product. Below are the topics to cover in this section.

- Goal and scope definition: goal, functional unit, system boundary, data category.
- Life cycle inventory analysis: data collection, database, data computation, allocation, recycling.
- Life cycle impact assessment: classification, characterization.
- Life cycle interpretation: contribution analysis (key issue identification).

The environmental parameters of the water kettle together with its life cycle data were identified in chapter 1. Based on this information, product composition and the life cycle data of the water kettle are presented in Tables 12 and 13, respectively. With the data in these two tables, we will show you how to perform LCA of a product and obtain key issues and environmental profile of the product.

Each of the four LCA phases is described in the following sections. Not only methods but also applications to water kettle of the methods are delineated below.

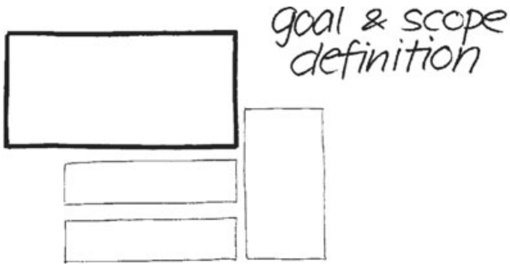
Table 12 Product composition of a water kettle.

Component	*Material*	*Weight (g)*	*Weight (%)*
Housing	PP	330.00	38
Packaging	Card board	200.00	23
Heater	Stainless steel	120.00	14
Lid	PP	80.00	9
Cable (PVC)	PVC	72.00	8
Cable (Cu)	Cu	48.00	6
Switch unit	PA	20.00	2
Total		870.00	100

Table 13 Life cycle data of a water kettle.

Life cycle stage	*Description*	*Data*
Use of raw materials	See Table 12	See Table 12
Manufacture (including components manufacturing)	Electricity was the only input to the manufacturing of components and assembly of water kettle.	Electricity consumption for the manufacturing of housing, packaging and heater was 0.5, 0.2 and 1.5 kWh, respectively. There are two types of product assembled, model A and model B. Production volume of model A and B is 7650 and 8900 units/month, respectively. Total electricity consumed in manufacturing (assembling) of both models was 10 000 kWh per month.
Distribution	The distribution is done within Europe by 40-ton trucks.	The average distance for transport is 3000 km.
Product use	Use scenario: heating ½ liter of water to prepare tea or coffee in an office, 3 times a day, 5 days a week, 50 weeks a year. The total uses add up to 2250 times over the 3 year lifetime of the product.	Electricity consumed is 0.0545 kWh per use.
End of life	Disposal via municipal waste route.	The ratio of recycling, incineration, and landfill is 50%, 20%, and 30%, respectively.

2.3.1 Goal and scope definition



This is the first of the four LCA phases. It defines goal of the LCA study and scope of the product system to be analyzed and assessed. The scope definition delimits conditions, assumptions and limitations of the LCA study. Before commencing discussion, however, one has to have a clear mission statement from the management for launching LCA study. Below is the mission statement for performing LCA of water kettle.

Reason for performing LCA of water kettle

Our company wants to undertake an LCA study of a water kettle to secure data for a new model to be redesigned with improved environmental performance and for communicating environmental aspects of the improved water kettle to the market. The LCA data will then be used to identify environmentally weak points for product improvement for product designers, developers, and managers within the company. In addition, environmental aspects of the improved product will be communicated to retail and institutional consumers as well as Business-to-Business (B2B) consumers in the supply chain in the form of an Environmental Product Declaration.

Goal definition

Goal definition specifies the objectives and applications of the LCA study. There are three specific questions to be addressed.

- Why: Why do you undertake the LCA study? State the reasons for undertaking the LCA study.
- Who: Who are the target audiences? Identify target audiences, direct or potential, to whom the LCA results will be distributed.
- What: What are the application areas? Identify direct and potential areas of application of the LCA results.

Answers to the three specific questions applicable to the water kettle LCA are:

(i) Why: To generate environmental profile data and to identify key issues (environmentally weak points) of the water kettle.

(ii) Who: Product designers, developers, and managers within the company, and retail and institutional level consumers as well as Business-to-Business (B2B) consumers in the supply chain.

(iii) What: Redesign of the reference product, water kettle; Environmental profile data to meet the requirements of the ECODESIGN regulations; and Environmental communication to the market in the form of an EPD.

Once goal definition is completed, the depth and breath of the subsequent LCA elements are determined. For instance, the manufacturing data of the water kettle and its parts/components should come from the manufacturing sites, not from literature, for the key issues identified are used for improving the water kettle.

Scope definition

Scope definition addresses issues related to function, system boundary and data category, among others. Below are specific questions of each issue and answers to each issue.

Function

There are three specific questions to address under the function:

- What is the function of the product?
- What is the quantified measure of the function provided by the product or functional unit?
- What is the amount of product to fulfill the product function or reference flow?

Answers to these questions are:

(i) *Function*: A product function is what the product provides to a user. Depending on the viewpoint of the user, the product function may vary. However, the basic function of the product remains the same. For instance, the basic function of an automobile is to provide transport means for the user. To some, however, the automobile can be the symbol of a social status of the user. This simple example illustrates possible complication in identifying the product function. This is particularly true for the multi function audiovisual equipments and IT products. In the case of multi functional products, the basic function of a product from the perspective of the user should be the ground for selecting the function of the product.

(ii) *Functional unit*: A functional unit is a measure that allows quantification of the product function chosen above. Function is abstract, however, functional unit is not. It represents performance of the functional outputs of the product. A key question here is to choose a measurable metrics to quantify the abstract function. For instance, the function of a beverage container (bottle or can) is to store beverage. The functional unit of the beverage container, assuming it is 500 ml in volume, would be 500 ml storage volume.

(iii) *Reference flow*: Reference flow is a measure of the product amount to realize the function, hence functional unit. Simply put, it is the amount of product that is necessary to fulfill the function. Following the same example of a beverage container of 500 ml volume, the reference flow is one aluminum can of 13 g in weight and one glass bottle of 70 g in weight, provided that the weight of the aluminum can and glass bottle is 13 g and 70 g, respectively.

Function, functional unit and reference flow of the water kettle can be defined as shown below. In addition, product and product system can also be described to clarify the LCA implementation.

Product:	Water kettle company model A.
Product system:	Water kettle company-model A plus all related processes and activities consist of a product system. This includes components and materials manufacturing, distribution, product use

	and end of life of the product. In addition, all transport occurring and energy used not only for the product itself but also for all the elements in the product system is included in the product system.
Function:	Heating potable water for preparing tea or coffee.
Functional unit (fu):	Heating 0.5 liter of potable water to boiling point.
Reference flow:	One water kettle.

System boundary

Specific questions to address when defining the system boundary are:

- What are the unit processes and activities associated with the product, and interrelationships among them?
- What are the criteria for including and excluding certain processes and activities? – Decision rule for mass inclusion.
- What processes and activities are included in a product system? – Process tree.
- What are the other requirements in setting the system boundary?
- What would be the system boundary of each of the five life cycle stages?

Answers to the questions are:

(i) *Unit processes, activities and their interrelationship*: A product cannot exist without materials, parts and components, and energy. Thus, a concept called product system emerges as discussed in chapter 1 and section 2.2. A product system provides the system boundary for LCA. A product system consists of unit processes and activities associated with the product throughout its entire life cycle. There can be numerous processes and activities included in the product system; some are significant while others are minor.

Based on the product composition, unit processes and activities associated with the product can be identified. The product composition, main source of the process information, can be derived either from bill of material (BOM) or by disassembling the product. Information on various activities is derived from the entire life cycle of the product.

(ii) *Decision rule for mass inclusion*: A product system should include seemingly significant processes and activities. This is necessary from a practical and economic viewpoint. A decision rule based on mass or energy is often used to determine product system and to justify excluding less significant processes from the product system.

Decision rule for mass inclusion criteria includes: (i) if a unit process's weight fraction of the product is less than a certain percentage, then exclude it; (ii) if the excluded unit process, however, is considered environmentally significant (e.g. toxic chemicals), then it should be included.

As shown in Table 14, cumulative weight percentage is calculated using the product composition information in Table 12 to apply for the decision rule (here 75% has been chosen). Cumulative weight means that the weight of each component of the product is summed up. Then any components outside the 75% limit are excluded from the product system. Only three components are included in the water kettle product system as marked bold in Table 14.

Table 14 Components of the water kettle included in the product system (marked in bold).

Component	*Material*	*Weight (g)*	*Weight percent (%)*	*Cumulative weight percent (%)*
Housing	**PP**	**330.00**	**38**	**38**
Packaging	**Card board**	**200.00**	**23**	**61**
Heater	**Stainless steel**	**120.00**	**14**	**75**
Lid	PP	80.00	9	84
Cable (PVC)	PVC	72.00	8	92
Cable (Cu)	Cu	48.00	6	98
Switch unit	PA	20.00	2	100
Total		870.00	100	

(iii) *Process tree*: A process tree is a collection of unit processes and activities in a product system showing their interrelationship. Each unit process or activity is represented by a box, and the interrelationship is shown with directional arrows. Once unit processes and activities are chosen to be included in the product system, a process tree can be drawn.

Processes and activities included in the water kettle product system are:

Housing, packaging, and heater, materials required for each of the three components, manufacturing of the water kettle (assembly), distribution, product use and end of life of the water kettle. Figure 11 shows the process tree of the water kettle consisting of unit processes and activities.

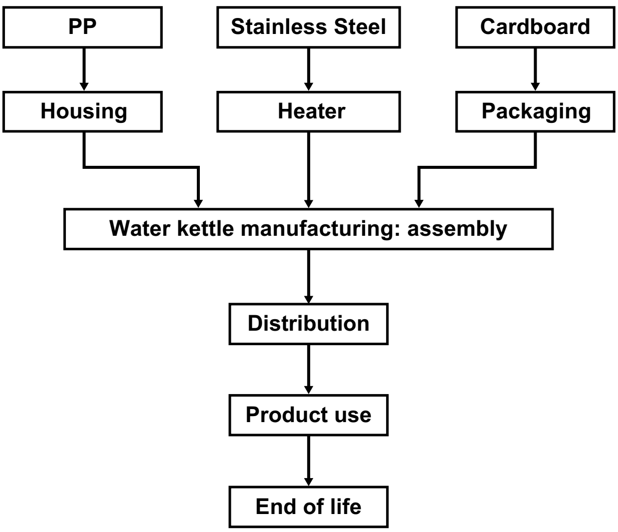


Figure 11 Process tree of the water kettle.

In all unit processes and activities, energy and transport are integral parts. In other words, data collection must include resources consumption and emissions not only from the materials but also from the energy and transport part. However, it is customary not to show energy and transport in the process tree.

(iv) *Other requirements*: There are other requirements to consider in setting a product system. They are temporal, geographical and technological boundaries. Application of these boundaries to the water kettle case shows:
Temporal boundary: within the last 5 years.
Geographical boundary: manufactured, used and disposed of in Europe.
Technological boundary: average of current technologies.

(v) *System boundaries of the five life cycle stages*: A clear description of the system boundary of each of the five product life cycle stages is given below. This information will be used in preparing an EPD of the water kettle in chapter 5.

Use of Raw Materials:	It includes natural resources extraction from nature and production of raw and ancillary materials from the resources.
Manufacture:	It includes manufacturing of parts and components in the suppliers manufacturing sites, and assembly of the water kettle at the manufacturing site of our company.
Distribution:	It includes transport from our company to major European markets. The distribution distance is approximately 3000 km within Europe by 40-ton trucks.
Product use:	The amount of electricity required heating 0.5 l of potable water in a water kettle to prepare tea or coffee was 0.0545 kWh per use. The water kettle provides heated water for 3 times a day, 5 days a week, and 50 weeks a year over the 3 years.
End of life:	It includes collection, treatment and disposal of the waste water kettle. Approximately 30% of the waste water kettles are landfilled, 20% incinerated and 50% recycled at the end of the product's life.

Data category

The specific question to address here is:

What kind of data categories and parameters should be considered?

The answer to the question is:

Data collection is the most labor intensive and time-consuming task. In order to minimize the effort and facilitate the data collection task, predefined data category and parameters should be fixed. In essence, input and output data to and from unit processes and activities of a product system determines the LCA results. Table 15 shows data category and parameters in LCA. Data parameters are the ones that actually measure the magnitude of the data. The data parameter is often called inventory parameter.

Table 15 Data category and parameters.

Broader data category	*Specific data category*	*Parameters (illustrative)*
Input	Raw materials	Crude oil, Iron ore
	Ancillary materials	Solvent, Process materials
	Energy	Electricity, LNG
Output	Products	Water kettle
	Co- and/or by-products	Slag
	Emissions to air	CO_2, Methane
	Emissions to water	Phenol; Organic carbon
	Emissions to land	Solid waste, Heavy metals

From the definitions specified in the goal and scope definition phase, the depth and breadth of the tasks in the remaining other three LCA phases is determined. Based on the system boundaries of the product and using the data parameters chosen, data collection begins in the life cycle inventory analysis phase.

2.3.2 Life cycle inventory analysis

Now the first phase in LCA, goal and scope definition, has been completed. The next phase, the life cycle inventory analysis, follows. The goal of the life cycle inventory analysis phase is to collect data in the first place, and then process the collected data to generate the inventory analysis results. This phase is the most time consuming of all the four phases in LCA and deals with the topics listed below:

- Data collection: How to collect data?
- Database: What is the database and how to use it?
- Data computation: How to calculate life cycle inventory data in the light of many processes and activities in a product system?
- Allocation: What is allocation and where to apply it?
- Special case of allocation: Recycling: What to consider in the case of waste recycling as raw materials?

The topics listed above are successively described below, according to the order of appearance in the list.

Data collection

The data collection involves three consecutive steps in series. They are: preparing for data collection, data collection, and data validation (ISO 14041, 1998).

Preparing for data collection

Input and output data of the unit processes and activities in a product system (shown in a process tree) are collected. Data categories and parameters have already been determined under the scope definition. Depending on the goal of the LCA study, one should set target data quality requirements. In general, specifying data source is the first step in setting the target. For instance, manufacturing data should be on-site or product specific data, raw and ancillary materials as well as energy and end of life data should be derived from the database, those not listed under the database may originate from literature, among others.

In order to collect on-site data, typically manufacturing data of products and components, a data questionnaire has often been used. There can be a variety of data questionnaires possible. Table 16 shows one of the data questionnaire formats where a heater was chosen as an illustrative example. Each manufacturing site and product manufactured at the site can be unique. Thus, the data questionnaire must be modified to reflect the specific situation.

Table 16 One possible form of data questionnaire format with illustrative data for a heater.

Product name: Heater			Contact details: Mr. John
Manufacturer: Company			
Data collection period: from January 1, 2003 to December 31, 2003			
Manufacturing process information: it should include process schematic diagram			
Input data			
Raw and ancillary materials and energy used			
Parameter	*Unit*	*Quantity*	*Country of origin*
Stainless steel	kg	0.5	Korea
Transport			
Transport mode	*Distance traveled*		*Mass transported*
40 ton trailer truck	3000 km		20 ton
Output data			
Emissions to Air, Water, and Land			
Parameter	*Unit*		*Quantity*
CO_2	g/kg product		3650

Data collection

In general, data collection period covers one year. In addition, data should be collected from important unit processes and activities, and then move towards less important ones. Table 17 shows possible data sources for various data categories.

Often, there exists a database of selected raw and ancillary materials, energies, and various activities and processes, such as landfill, incineration, and transport in private or public domain. Using a database greatly simplifies the data collection task. Details of the database will be discussed under the database section. However, attention must be paid when using the databases because system boundaries and assumptions made in developing the databases are not transparent or do not match with the product system boundary under study. Thus, the use of database may not be suitable for a specific LCA study.

Table 17 Possible data sources for various data categories.

Input data	
Raw and ancillary materials, parts and components	Purchasing records, bill of materials, process schematic diagram, production records.
Energies	Source of electricity (where does the electricity come from?), amount of electricity, fuels and steam used.
Output data	
Emissions to air, water and land	Measured emission data, calculated emission data, legal discharge limits.
Products and co-/by-products	Amount of products, by-/co-products (unit or mass or volume) manufactured, unit product weight and wholesale price.

Manufacturing data can be collected using data questionnaire similar to the one shown in Table 16. This applies not only to the main product but also parts and components of the main product. In addition, it is desirable to collect on-site data for transport by specifying the mode of transport, transport distance, the amount transported in terms of weight and/or volume, and the type of fuels used, etc.

Product use stage data are highly dependent upon consumer survey results. Since the manufacturer has no control over the consumers' behavior, reliability of the survey results can vary significantly. Nonetheless, the product use stage scenario must be developed, either by taking the consumers' survey results by the manufacturer or consumer organizations or literature. Typical data parameters include average use time, average use frequency or intensity, energy and resource (e.g., water) consumption, and emissions to air, water, and land during the product use stage.

End of life stage data should reflect the actual disposal pathways and actual operational practices where the products are disposed of. Typical data to collect include: collection means and distance to transport from the source of generation to the point of treatment and ultimate disposal; treatment means such as recycling, reuse and incineration, and ultimate disposal means such as landfilling.

Some of the data should be derived from the actual site; however, others can be obtained from databases and literature.

Data validation

Before data computation, the collected data should be verified and validated. Verification methods may include mass and energy balance in a process or comparison with the emission factors for fuels. For instance, simple mass and/or energy balance around a unit process can verify the validity of the collected data.

Database

Life Cycle Inventory database (LCI DB) is a life cycle inventory data of a material, energy, or process that was developed previously using average data. Either government or private consulting companies develop databases for common materials (e.g., copper wire, poly propylene, cement), energies (e.g., electricity, gasoline, steam), transport (e.g., truck, ship, train), processes (e.g., welding, grinding), and end of life

activities (e.g., incineration, landfill). Thus, using of LCI DB greatly simplifies the life cycle inventory analysis.

The system boundary of the LCI DB spans from resource extraction to manufacture of the materials, energy and processes. The latter includes all activities up to the factory gate of the manufacturing plant. For instance, the system boundary for LCI DB of stainless steel plate includes all unit processes associated with the stainless steel plate up to the point of exiting the manufacturing plant gate. Often this type of system boundary is termed cradle to gate (CtG). Here, “cradle” represents resources coming from nature, and “gate” represents the conclusion of the manufacturing plant process at the exit gate. For the end of life activities, the system boundary spans from waste generation to the ultimate disposal.

Table 18 shows the database to be used for the water kettle LCA. Note that this is a simplified database. A real database contains many more parameters. In the case of stainless steel DB, for instance, Table 18 indicates that four different kinds of resources were used and one emission was generated to make 1 kg of stainless steel plate in a system spanning from the resource extraction to the exit gate of the steel manufacturing plant.

Table 18 Database for the water kettle LCA (simplified version).

	Parameter	*Category*	*Unit*	*Total*
PP	Crude oil	Raw	g	1200
(1 kg)	CO_2	Air	g	1800
	NO_x (as NO_2)	Air	g	10
	SO_x (as SO_2)	Air	g	11
	VOC	Air	g	9.60
Cardboard	Crude oil	Raw	g	114
(1 kg)	CO_2	Air	g	467
	NO_x	Air	g	3.96
Stainless steel	Crude oil	Raw	g	294
(1 kg)	Coal	Raw	g	779
	Chromium	Raw	g	203
	Iron ore	Raw	g	655
	CO_2	Air	g	3650
Electricity	Coal	Raw	g	50
(1 kWh)	CO_2	Air	g	290
	Methane	Air	g	0.53
	SO_2	Air	g	1.18
Transport	Crude oil	Raw	g	28
(40 t Truck, 1 ton-km,	CO	Air	g	0.51
50% loaded)	CO_2	Air	g	93
Incineration	Coal	Raw	g	0.16
(1 kg waste)	Crude oil	Raw	g	0.70
	CO_2	Air	g	3.56
	NO_x (as NO_2)	Air	g	0.13

Table 18 (Continued)

	Parameter	*Category*	*Unit*	*Total*
Landfill	Crude oil	Raw	g	0.95
(1 kg waste)	CO_2	Air	g	19
	Methane	Air	g	1.97
	SO_x (as SO_2)	Air	g	0.03
Recycling	Coal	Raw	g	7.88
(1 kg waste)	Crude oil	Raw	g	–75
	Iron (ore)	Raw	g	–106
	CO_2	Air	g	–200

(Note: A negative value for the recycling means that there is an environmental benefit or positive environmental impact accrued from recycling, not adverse environmental impacts.)

Data computation

The data computation involves three steps in series to obtain life cycle inventory results. They are: relating data to unit process, relating data to functional unit, and data aggregation (ISO 14041, 1998). There are occasions where allocation and special cases of allocation (recycling) need to be considered.

Relating data to unit process

Relating data to the unit process means dividing input and output data by the mass of the main output (part, component, material or product) of the unit process in the context of data computation. This division results in input and output data expressed as per unit mass of the main output of the unit process. Often times the division results are called environmental load of the unit process. Environmental load represents resources consumed and emissions generated in a unit process or product system.

Relating data to functional unit

This is the same division as the previous one. The only difference is that data related to the unit process are now divided by the main output of the product system, not by the output of the unit process.

The calculation of the environmental load of a product system follows a step-by-step procedure. First is the calculation of environmental load on the unit process level (process A in Figure 12). The same calculation repeats for the unit process level (process B in Figure 12). If there are components (or parts) needed for the manufacturing of the final product, then the environmental load of the component system must be computed. Subsequently calculate the environmental load of the entire product system. This result is called inventory result of the product system or simply inventory result of the product. (Note that product means product system in the context of LCA.)

When calculating the environmental load of a part of the entire product system (e.g., component manufacturing system for the final product), the fractional contribution of each unit process to the main output of the component system must be known. Multiplying the fractional contribution by the unit environmental load of the unit process and then summing up over the entire unit processes, enables one to obtain the unit environmental load of the component system.

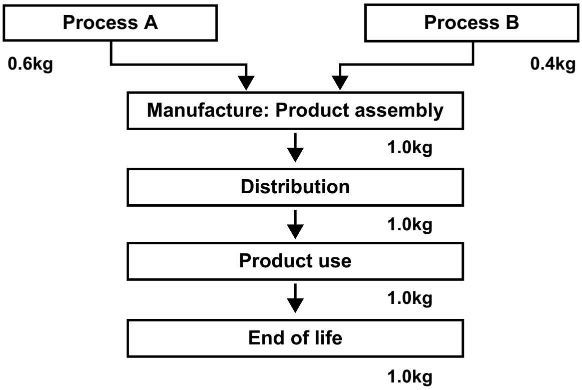


Figure 12 Process tree showing fictitious product system.

The same logic applies to the calculation of the environmental load of the entire product system. In other words, the fractional contribution of each component system to the main output of the entire product system must be known. Then multiply the fractional contribution by the unit environmental load of each component system and then sum them up over the entire component systems. In addition, the environmental load of other life cycle stage (e.g., manufacture, product use, distribution, end of life) should also be added to the environmental load from all the component systems to obtain inventory data of the entire product system.

Let's assume that you have two processes to make a product. Figure 12 shows the process tree of a hypothetical product system. Figure 12 does not, however, contain component systems to simplify the computation.

In essence, the computation logic is based on multiplication between the unit environmental load of each unit process or life cycle stage and its fractional contribution to the product. In Figure 12, 0.6, 0.4, and 1.0 represent fractional contribution of unit process A, unit process B, and each life cycle stage, respectively, to the product. The computation logic can be expressed as (EL process A) × (0.6) + (EL process B) × (0.4) + (EL manufacture) × (1.0) + (EL distribution) × (1.0) + (EL product use) × (1.0) + (EL end of life) × (1.0) = EL of the product system. The EL of the product system is the basis for the life cycle inventory result of the product.

Data aggregation

As can be seen from the computation logic shown above, inventory parameters from different unit processes and life cycle stages are aggregated. For instance, inventory parameter values from process A and process B are aggregated or added if it is the same parameter. This is called data aggregation. The aggregation simplifies data presentation; however, transparency of the data disappears. Aggregating data from the unit processes related to functional unit results in a life cycle inventory result.

Allocation

When there is more than one output or more than one input in a unit process, allocation of the environmental load is needed. Allocation is a process of partitioning the

input (materials and energies) into and the output (emissions and co-/by-products) from a unit process to its main output. Allocation requires an allocation factor. The most common allocation factor is based on physical quantity (mass, volume, or energy content) and economic value (sales price or net cost).

In the case of the water kettle, two models, Model A and Model B are assembled in the same factory. Electricity used during the assembly was the only source of input. There were no outputs other than the two models of water kettle. Since we perform LCA for Model A, the electricity consumption for the model A must be secured from the total electricity consumption data. Thus, allocation is necessary and the allocation factor based on allocation criteria, whether economic value or physical quantity, should be determined. Table 19 shows that the allocation factor for model A based on economic value was 0.38. This means that we can obtain electricity used for the assembly of Model A by multiplying this allocation factor by the total electricity used in the manufacturing process of the water kettle factory.

Table 19 Allocation factor based on economic value.

Type of model	*Unit produced (unit/month)*	*Sale price (Euro/piece)*	*Total sale price (Euro)*	*Allocation factor (%)*
Model A	7 650	18	137 700	38.2
Model B	8 900	25	222 500	61.8
Total	16 500	43	360 200	100.0

There are two different cases where allocation can be considered: a multi output process and a multi input process. The multi input process has more than one input into a process (e.g., the incineration process where more than one type of wastes enter into the incineration process). In this case, allocation deals with the allocation or partitioning of the output (e.g., waste flue gas, dioxin, and ash) to an input material (different wastes) into the process. The multi output process has more than one output in the form of co-/by-products or other products. These co-/by-products, however, must possess economic value. Allocation in Table 19 was a multi output case.

To be practical, we recommend that the allocation factor should be derived from the economic value first, and if that is not relevant, then physical quantity should be used.

Special case of allocation: Recycling

Recycling denotes an act of returning materials from wastes to raw materials for the same or different product. The use of recycled materials for the manufacturing of new product reduces the virgin material consumption. Since environmental load of the virgin raw material is greater than that of the recycled raw material, the use ofrecycled material leads to the reduction of the environmental load of the new product system. Thus, there is a need to allocate the environmental load saved between the two product systems when the recycled material is used for the manufacturing of another product.

Figure 13 depicts a simple product system with recycling of its waste. In this figure not all wastes generated are disposed of. Instead, the recycled portion of the waste is processed in a recycling plant. The recycled material then is used either in the same product system (i.e., recycled back to the manufacturing of the same

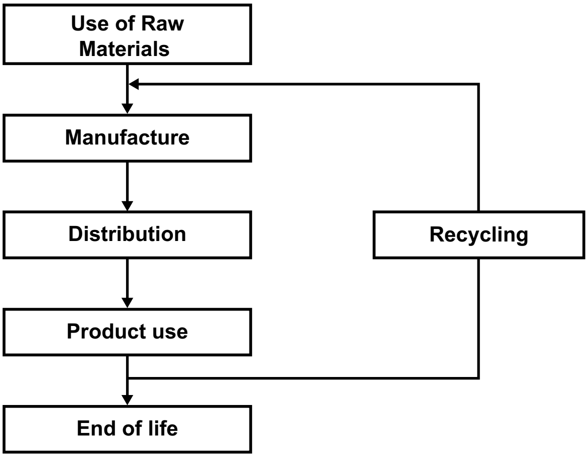


Figure 13 Simplified product system with waste recycling.

product, e.g., aluminum can is recycled back to make new aluminum can) or in another product system (i.e., recycled to the manufacturing of another product, e.g., aluminum can is recycled to make aluminum window frame).

Although there are many allocation methods for the latter case (use of recycled material for another product: also called open loop recycling), the application of those methods is difficult. This is because specific information of the fate of the recycled materials in the other product systems is often unavailable. Reason being is that the use of recycled material other than for the manufacturing of the same product is difficult to trace. For information, allocation methods for the open loop recycling case include closed loop approximation, avoided impact, cut-off, and the 50/50 methods. Of these, the most practical method envisaged is the closed loop approximation method.

The basic assumption of the closed loop approximation method is that recycled material is used as raw material of the same product, and no quality degradation occurs in the recycled material. This allows recycled material to be considered just like virgin raw material. In other words, recycled materials simply supplement virgin raw materials.

Allocation of environmental load by the closed loop approximation method is shown in Table 20. For illustrative purpose, let's assume that environmental load (in points) of virgin material, end of life stage (disposal), and end of life (recycling) are 300 points/kg, 200 points/kg, and 100 points/kg, respectively. Further assume that recycling ratio is 60% of the wastes generated such that raw material consists of 40% virgin and 60% recycled materials. Since other life cycle stages including manufacture, distribution and product use are not affected by allocation, the environmental load of these life cycle stages are not considered here.

Comparing the environmental load values between two different cases: one with recycling and the other without recycling, the use of recycled materials reduces the environmental load of the product system. The greater the recycling ratio is, the greater the reduction of the environmental load of the product system becomes.

Table 20 Environmental load of each life cycle stage due to recycling.

Life cycle stage	*Allocation of EL due to recycling*	*EL with recycling (points/kg)*	*EL without recycling (points/kg)*
Use of raw materials	Net virgin material use = 300/kg $\times$ 0.4 kg = 120	120	300
End of life (disposal)	Waste disposed of = 200/kg $\times$ 0.4 kg = 80	80	200
End of life (Recycling)	Amount recycled = 100/kg $\times$ 0.6 kg = 60	60	0
Sum		260	500

Thus, recycling is a viable option in mitigating environmental load of a product, and the recycling feature should be actively incorporated into the design of eco-products.

We recommend for simplicity and practicality the closed loop approximation method for allocation in the case of open loop recycling. However, more sophisticated method such as the avoided impact method can be used if desired (Lee and Inaba, 2004).

A summary of the life cycle inventory analysis of the water kettle case is presented below.

- Process tree with material and fractional contribution: See Figure 11.
- The LCI database: see Table 18.
- Life cycle inventory data collection and calculation

I. Data from the use of raw materials stage (extraction of resources from nature to production of raw and ancillary materials)
   - Amount of raw material required for the three components
     PP for housing (w/handle) = 330 g
     Cardboard for packaging = 200 g
     Stainless steel for heater = 120 g
   - Calculation of the EL of the production of PP, cardboard, and stainless steel for the three components
     DB_{PP}/kg $\times$ 0.33 kg/housing
     $DB_{cardboard}$/kg $\times$ 0.2 kg/packaging
     $DB_{stainless\ steel}$/kg $\times$ 0.12 kg/heater
   - Total EL from the use of raw materials stage
     Sum of the EL from the production of PP, cardboard, and stainless steel for housing, packaging and heater. Here, as we took the 75% decision rule for mass inclusion, we must adjust the data for the three components.
     Adjusted EL = actual EL $\times$ 1/decision rule for mass inclusion factor = (EL (PP) + EL (cardboard) + EL (stainless steel))/0.75

II. Data from manufacture stage (components manufacturing and water kettle assembly)

(Continued)

Electricity was the only energy input to the assembly of water kettle, and manufacturing of housing, packaging, and heater. In addition, there were no other outputs except the housing, packaging, and heater from each process. In other words, wastes and scraps were not generated during the manufacture stage. Clearly, this is an oversimplified case.

– Calculation of electricity consumed and EL for Model A
  Electricity consumed for model A = 10 000 kWh/month × (0.38)/(7650 unit/month) = 0.5 kWh/water kettle
  EL of water kettle assembly = $DB_{electricity}$/kWh × 0.5 kWh/water kettle
– Calculation of EL of the three components.
  Electricity consumed for housing = 0.5 kWh
  Electricity consumed for packaging = 0.2 kWh
  Electricity consumed for heater = 1.5 kWh
  EL of housing = $DB_{electricity}$/kWh × 0.5 kWh/housing
  EL of packaging = $DB_{electricity}$/kWh × 0.2 kWh/packaging
  EL of heater = DBelectricity/kWh × 1.5 kWh/heater
– Total EL from the manufacture stage
  Sum of the EL from the water kettle assembly, and manufacturing of housing, packaging and heater.

  Here, as we took the 75% decision rules for mass inclusion, we must adjust the data for the three components.

  Adjusted EL = Water kettle assembly EL + (sum of EL for the manufacturing of housing, packaging and heater manufacturing)/0.75

III. Data from distribution stage
  Distance traveled = 3000 km
  Mode of transport = 40 ton truck
  EL of the distribution = DB 40 ton truck/(ton-km) × distance traveled (3,000 km) × water kettle weight (0.87 kg/(1,000 kg/ton))

IV. Data from product use stage
  Electricity used per use = 0.0545 kWh
  Total number of uses = 2250 uses
  EL of the product use = $DB_{electricity}$/kWh × 0.0545 kWh/use × 2,250 uses

V. Data from end of life stage
  Percent of waste incinerated = 20%
  Percent of waste landfilled = 30%
  Percent of waste recycled = 50%
  EL of incineration = $DB_{incineration}$/kg × 0.2 × 0.87 kg/water kettle
  EL of landfilling = $DB_{landfill}$/kg × 0.3 × 0.87 kg/water kettle
  EL of recycling = $DB_{recycling}$/kg × 0.5 × 0.87 kg/water kettle

VI. LCI results of the water kettle
  Sum of the EL from the use of raw materials, manufacture, distribution, product use and end of life stage is the life cycle inventory results of the water kettle. See Table 21.

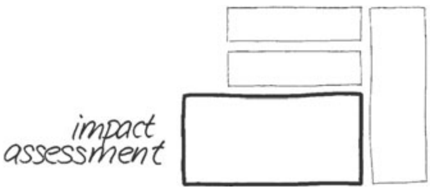
Table 21 shows the life cycle inventory analysis result of the water kettle. The results specify the values of the parameters of the water kettle during its entire life cycle stages. However, these values cannot be used directly to judge the environmental impact of the product because there are no judgment criteria except “less is better.”

The environmental impacts caused by the inventory parameters of the product, therefore, are assessed and quantified in the next phase, the life cycle impact assessment, where systematic methods for environmental assessment are used to convert the inventory results to environmental impact results.

Table 21 Life cycle inventory analysis result of the water kettle (unit: g/water kettle).

Parameter	*Use of raw materials*	*Manufacture*	*Distribution*	*Product use*	*End of life*	*Total*
Crude oil	605.48		73.34		−63.71	615.11
Coal	124.64	169.94		6 069.94	7.00	6 371.52
Chromium	32.48					32.48
Iron	104.80				−92.22	12.58
CO_2	1 500.53	995.59	241.43	35 561.25	−154.93	38 143.87
Methane		1.83		65.24	1.71	68.78
CO				1.33		1.33
VOC	4.22					4.22
NO_x (Air)	5.46				0.11	5.57
SO_x (Air)	4.84		4.05	144.70	0.03	153.62

2.3.3 Life cycle impact assessment



Now the second phase in LCA, the life cycle inventory analysis, has been completed. The next phase, life cycle impact assessment, follows. The goal of the life cycle impact assessment phase is to convert inventory results into the impacts on the environment. This phase deals with the topics listed below:

- Classification: link inventory parameters to relevant impact categories.
- Characterization: it consists of three steps:
  - First, quantification of the environmental impact of an inventory parameter belonging to a given impact category.
  - Second, repeat the first step for all inventory parameters belonging to the same impact category and sum them up.
  - Third, repeat first and second steps for all impact categories.

Figure 14 illustrates the relationship between life cycle inventory analysis and life cycle impact assessment.

Figure 14 shows that the connecting link between life cycle inventory analysis and impact assessment is the impact category marked in shade. Inventory parameters from the life cycle inventory analysis are connected or linked to the relevant impact categories. This process is called classification.

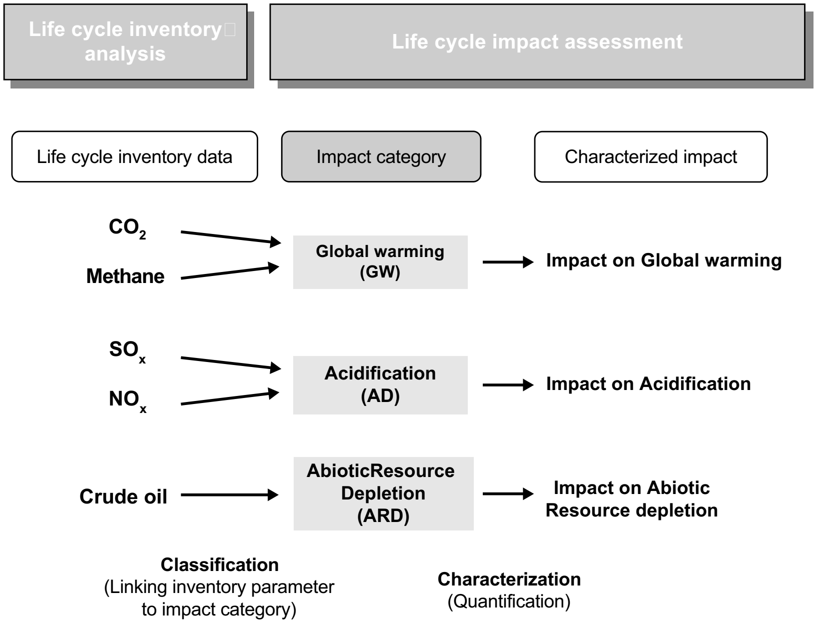


Figure 14 Relationship between life cycle inventory analysis and life cycle impact assessment.

Before connecting inventory parameter to impact category, prior knowledge of the relationship between them is required. It should also be noted that one parameter can affect more than one impact category. Table 22 displays the classification result of the water kettle.

Table 22 Classification of the water kettle.

Parameter	*Impact categories*				
	GW	*AD*	*EU*	*POC*	*ARD*
Crude oil					✓
Coal					✓
Chromium					✓
Iron					✓
CO_2	✓				
Methane	✓			✓	
CO				✓	
VOC				✓	
NO_x		✓	✓	✓	
SO_x		✓			

Once the inventory parameters are classified into respective impact categories, relative contribution of each inventory parameter to a given impact category is

quantified using a characterization factor. The quantification result is the impact on the given impact category. This quantification process is called characterization.

Before quantifying or characterizing the relative contribution of the inventory parameter to the relevant impact category, one needs to understand the cause-effect chain concept between the cause (inventory parameter) and the effect (environmental impact). A cause-effect chain is depicted in Figure 15 for the case of acidification, causing the so-called acid rain effect on the environment. The starting inventory parameter is acid substance in the form of gas or liquid. Once the acid substances are released into the environment, a series of effects on the environment occur.

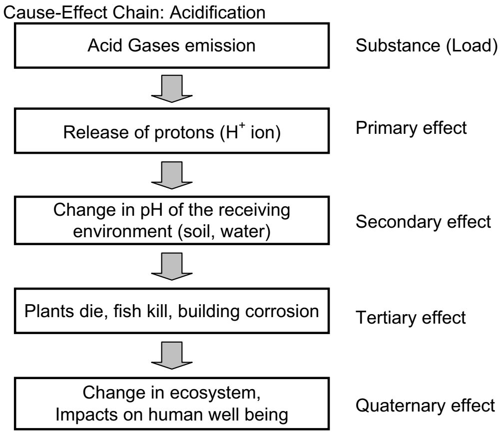


Figure 15 Cause-effect chain of acidifying gases in the environment.

From Figure 15, only one type of effect or impact is chosen. Normally, LCA practice dictates which effect is chosen in the life cycle impact assessment. Since the objective is to quantify the relative contribution from each inventory parameter to its effect, a scientifically quantifiable effect is chosen. In the case of acidification shown in Figure 15, the primary effect is chosen in practice. Here, the relationship between acid substance and the number of protons the substance liberates is established. The number in this relationship is termed equivalency or characterization factor. All these characterization factors are readily available in any LCA books.

Table 23 shows typical impact categories with the names and units of the characterization factors.

Table 24 shows characterization factors of several inventory parameters. These factors will be used in the characterization of the water kettle.

Once characterization factors are available, environmental impacts by inventory parameters on a given impact category can be quantified using equation (1).

$$\text{Characterized impact (CI) of an inventory parameter} = \text{Load of the inventory parameter} \times \text{characterization factor of the parameter} \quad (1)$$

Table 25 shows the characterized impact result of the water kettle. The inventory parameter with its load is multiplied by the corresponding characterization factor in

Table 23 Name and unit of characterization factor of typical impact categories.

Impact category	*Characterization factor name*	*Characterization factor unit*
Global warming	Global warming potential (GWP)	g CO_2-eq/g
Ozone layer depletion	Ozone depletion potential (ODP)	g CFC11-eq/g
Acidification	Acidification potential (AP)	g SO_2-eq/g
Eutrophication	Eutrophication potential (EP)	g PO_4^{3-}-eq/g
Photochemical oxidant	Photochemical oxidant creation potential (POCP)	g C_2H_4-eq/g
Abiotic resource depletion	Abiotic resource depletion potential (ADP)	1/yr*

(Note: * is the unit from U_j/D_j, where U_j = worldwide use of the jth resource, kg/yr; D_j = the size of the deposit of the jth resource, economically extractable, kg)

Table 24 Characterization factors used in the water kettle case.

Parameter	*Characterization factor*				
	GWP (g CO_2 eq/g)	*AP (g SO_2 eq/g)*	*EP (g PO_4^{3-} eq/g)*	*POCP (g ethene eq/g)*	*ADP (1/yr)*
Crude oil					0.0248
Coal					0.00344
Chromium					0.00381
Iron					0.00721
CO_2	1.00				
Methane	23.00			0.006	
CO				0.027	
VOC				0.416	
NO_x		0.70	0.13	0.028	
SO_x		1.00			

all impact categories. For instance, in the case of methane, the CI of methane is the load of methane (68.78 g/water kettle) multiplied by its characterization factor (23 g CO_2-eq/g methane) and results in 1581.94 g CO_2-eq/water kettle. When summed up over all inventory parameters in a given impact category, the total characterized impact of that impact category is obtained.

As shown in Table 26, the product use stage is the most dominant source of impact followed by the use of raw materials stage. In the case of the end of life stage, environmental benefit occurred instead of adverse impact. Although there are significant differences in magnitude of characterized impact among different impact categories, however, one cannot compare them directly. This is because there are no relative

Table 25 Characterized impact of the water kettle.

Parameter	*Load (from Table 21)*	*Characterized Impact (CI)*									
		GW (g CO_2 eq/water kettle)		*AD (g SO_2 eq/water kettle)*		*EU (g PO_4^{3-} eq/ water kettle)*		*POC (g ethene eq/ water kettle)*		*ARD (g/water kettle-yr)*	
		GWP	*CI*	*AP*	*CI*	*EP*	*CI*	*POCP*	*CI*	*ADP*	*CI*
Crude oil	615.11									0.0248	15.25
Coal	6 371.52									0.00344	21.92
Chromium	32.48									0.00381	0.12
Iron	12.58									0.00721	0.09
CO_2	38 143.87	1.00	38 143.87								
Methane	68.78	23.00	1 581.94					0.006	0.41		
CO	1.33							0.027	0.04		
VOC	4.22							0.416	1.76		
NO_x	5.57			0.70	3.90	0.13	0.72	0.028	0.16		
SO_x	153.62			1.00	153.62						
Total			39 725.81		157.52		0.72		2.37		37.38

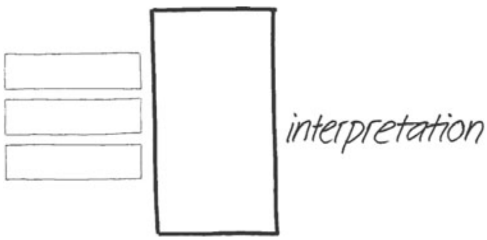
Table 26 Characterized impact of the water kettle per life cycle stage.

Impact category		*Life cycle stage*					*Total*
		Use of raw materials	*Manufacture*	*Distribution*	*Product use*	*End of life*	
GW	g CO_2 eq/ water kettle	1500.53	1037.65	241.43	37 061.70	−115.50	39 725.81
AD	g SO_2 eq/ water kettle	8.66	4.05		144.70	0.11	157.52
EU	g PO_x^{3-}eq/ water kettle	0.71				0.01	0.72
POC	g ethene eq/ water kettle	1.92	0.00	0.04	0.40	0.01	2.37
ARD	g/water kettle-yr	16.32	0.58	1.82	20.88	−2.22	37.38

weights applied to the impact categories in comparing the characterized impacts among different impact categories.

Both Tables 25 and 26 show the life cycle impact assessment result of the water kettle. However, these impact values cannot be used directly to pin point the environmentally significant processes and activities of the product (key issues) because there was no mechanism to interpret the impact result in this phase. The key issues of the product, therefore, are identified in the next phase, the life cycle interpretation, where systematic methods for identifying key issues are used to extract significant processes and activities of the product from the environmental impact assessment result.

2.3.4 Life cycle interpretation



Now the third phase in LCA, life cycle impact assessment, has been completed. The next phase, life cycle interpretation, follows. The goal of the life cycle interpretation phase is to interpret overall results of LCA and, more importantly, to identify environmentally significant issues from the life cycle impact assessment results. This phase deals with the topics listed below:

- Identification of significant issues: identify key processes, activities, and materials exerting significant impact on the environment.

- Evaluation of reliability of the LCA results: check the completeness and consistency of the LCA data, methods and assumptions, and evaluate the sensitivity of the LCA results with respect to the uncertainty in data and assumptions, in particular the allocation method.
- Report of the LCA results: report conclusions of the LCA results and recommendations if any.

Of the three major topics in the life cycle interpretation phase, only the identification of significant issues was covered under the mandatory LCA part of this chapter. This is not because other tasks are not important. On the contrary, the other two topics are vital in ensuring the credibility of the LCA results. This is particularly true when the LCA results are open to the pubic. However, internal use of LCA such as for the identification of environmental weak points in ECODESIGN can allow one to direct all the effort to the first topic listed above, and less effort to the rest of the two topics. Thus, the other two topics are treated under the optional elements of the LCA.

Significant or key issues are activities, processes, materials, components, or life cycle stages which have significant impact on the total impact of a product system. How much contribution from each issue is considered for the key issue depends on the arbitrary decision criteria made by the person who implements the LCA. Rule of thumb says that 1% has been traditionally used in judging whether the issues are significant or not.

A method called "contribution analysis" has been applied for the identification of key issues or weak points of a product system (ISO 14043, 2000). Typically characterized impact results have been used in the identification of key issues. Other results such as inventory results or weighted impact results can also be used.

Characterized impact results are, in general, expressed in a matrix, where rows list inventory parameters, and columns list unit processes and activities shown in the process tree. Table 27 displays the characterized impact for the global warming impact category of the water kettle, resulting from inventory parameters per life cycle stage.

Table 27 Characterized impact of the global warming impact category of the water kettle (unit: g CO_2-eq/water kettle).

Inventory parameter	*Unit processes and activities*					*Sum*
	Use of raw materials	*Manufacture*	*Distribution*	*Product use*	*End of life*	
CO_2	1 500.53	995.59	241.43	35 561.25	−154.93	38 143.87
CH_4		42.06		1 500.45	39.43	1 581.94
Sum	1 500.53	1 037.65	241.43	37 061.70	−115.50	39 725.81

The total impact of global warming of the water kettle shown in Table 27 is 39 725.81 g CO_2-eq/water kettle. Every entry of the characterized impact matrix is now divided by the total impact of the product system and expressed as a percentage of the total. Table 28 shows the results of this division. The percentage value in each entry in the matrix is the percent contribution made by each unit process, or activity associated with a specific inventory parameter, to the total global warming impact of the product system.

Table 28 Percent contribution by each entry on the matrix to the total global warming impact category of the water kettle (unit: %).

Inventory parameter	*Unit processes and activities*					*Sum*
	Use of raw materials	*Manufacture*	*Distribution*	*Product use*	*End of life*	
CO_2	3.77	2.51	0.61	89.52	−0.39	96.02
CH_4		0.10		3.78	0.10	3.98
Sum	3.77	2.61	0.61	93.30	−0.29	100

Assuming that the percent contribution from each cell in the matrix greater than 3% of the total impact is a key issue, the table reveals that: (i) the key unit processes and activities are the use of raw materials and the product use stage, and (ii) the key inventory parameter is CO_2 in both stages.

2.4 Optional elements of LCA

Optional elements in the life cycle impact assessment phase include normalization and weighting. However, there are no optional elements in the life cycle interpretation phase; thus, we have placed all elements in interpretation phase except the identification of significant issues in this section. Reasons for this decision were stated under the life cycle interpretation section. Following topics are covered in this section.

- Normalization: What is normalization and how to attain normalization?
- Weighting: What is weighting, how to generate weight, and what is the use of weighting?
- Evaluation of completeness, sensitivity and consistency check: What are the completeness, sensitivity and consistency check? How to evaluate completeness of the data, sensitivity of the results with respect to input data and allocation methods used, and consistency of the method applied in performing LCA?
- Conclusions and recommendation: What to report and recommend?

2.4.1 Normalization

A characterized impact is an impact on the environment exerted by a product. The geographical region affected by the impact can be local, regional or global, depending on the nature of the impact. For instance, global warming is a global impact, acidification is a regional impact, and photochemical oxidant creation is a local impact. In the same geographical regions, however, there are also other products. As a result, there are impacts from other products as well.

Let us say an impact of an impact category from all the different products in a given geographical region is N. If characterized impact of this impact category of a product from the same geographical boundary is divided by N, then the fractional contribution of the product's impact to the total impact in a given geographical region is known. The value of this fractional contribution is termed normalized impact (NI) of the product and N is termed normalization reference.

A normalization reference of an impact category based on person equivalent is calculated as shown in Equation (2).

$$N = \square \text{ (load of a parameter per year} \times \text{characterization factor of the parameter)/(population size of the geographical region)} \quad (2)$$

Where

N = normalization reference of an impact category, g × -eq/(pe-yr),

pe-yr = person equivalent-year,

A normalized impact is calculated as shown in equation (3):

$$NI = CI/N \quad (3)$$

Where

NI = Normalized impact of an impact category of a product, (pe-yr)/fu.

In essence, normalization is a process dividing the impact category's characterized impact of a product by the normalization reference of the same impact category. The value of NI represents the degree of relative impact caused by the product to the total impact of the geographical region.

The normalized impacts of the water kettle per life cycle stages are shown in Table 29. Normalization references used for GW, AD, EU, POC and ARD per person equivalent-year were based on 1995 data with the values of 5660 kg CO_2-eq, 56.4 kg SO_2-eq, 8.9 kg PO_4^{3-}eq, 7.4 kg ethene-eq, and 18.7 kg/yr, respectively (MOCIE, 2002). The most dominant impact category of the water kettle is global warming

Table 29 Normalized impact of water kettle per life cycle stage.

Impact category	*Total (millionth pe-yr/water kettle)*					*Total*
	Use of raw materials	*Manufacture*	*Distribution*	*Product use*	*End of life*	
GW	265.12	183.33	42.66	6548.00	−20.41	7018.70
AD	153.52	71.83		2565.60	1.95	2792.90
EU	79.78				1.12	80.90
POC	259.46	0.00	5.41	54.05	1.35	320.27
ARD	872.49	31.26	97.33	1116.58	−118.72	1998.94

followed by acidification and then abiotic resource depletion. This indicates that global warming, acidification and abiotic resource depletion are three most significant impacts on the environment caused by the water kettle. Note that normalization references vary depending on the geographical region chosen and the base year to which data was collected. For instance, the normalization reference of GW in 2000 was 5530 kg CO_2-eq/pe-yr (MOCIE, 2002).

2.4.2 Weighting

One important feature of normalization is that direct comparison of the magnitude of the impact among different impact categories can be possible as evidenced in Table 29. One implicit assumption in the normalization, however, is that relative significance among the different impact categories is the same. In reality, this is not the case.

The relative significance is also called weight and the weight reflects the value of the society or organization. Assigning weight is termed weighting. Thus, weighting in an LCA means the assignment of weight or relative significance to the impact categories based on social, ethical, and political values.

When weight is multiplied by normalized impact, the resulting impact is called weighted impact. Weighted impact (WI) of a product in an impact category can be expressed as shown in equation (4).

$$\text{WI of an impact category} = \text{weight of the impact category} \times \text{NI of the impact category} \quad (4)$$

When summed up over the all impact categories, the weighted impact of a product, WI, is obtained as shown in equation (5).

$$\text{WI} = \sum \text{WI of each impact category} \quad (5)$$

There are three categories of weighting methods commonly employed in the quantitative weighting process. They are panel method, monetization method, and target method.

The panel method is to ask a group of people for their opinion about the relative significance of the impact categories. The Delphi-like panel method is the most well-known panel method. It consists of four steps to generate weight.

(i) Gain a common understanding among the panel members on the importance of the impact categories.
(ii) Have each panel member assess the relative significance of each impact category based on common understanding.
(iii) Assess the results from the panel members and then present the results back to the members. Ask panel members to re-assign relative significance to the impact categories based on the group's results.
(iv) Determine weight of each impact category by taking average of the re-assigned weight from each panel member.

In general, a precautionary principle is explained to the panel members for gaining common understanding on the significance of impact categories. The

precautionary principle consists of four elements (Udo de Haes, 1996). They are: the degree of scientific uncertainty, scale of the impact, duration of the impact, and the degree of irreversibility. Those impacts with scientifically unknown consequences are considered more serious than those with scientifically known consequences. Global impacts are considered more serious than regional and local impacts. An impact with longer recovery time is considered more serious than that with shorter recovery time. Irreversible impacts are considered more serious than reversible ones.

Monetization methods are to ask a group of people to assign monetary values to different impact categories. The Environmental Priority Strategy system (Steen, 1999) method is a well-known monetization method. It is based on society's willingness to pay to avoid damage resulting from resources depletion and emissions of pollutants to the environment. An inventory parameter is assigned monetary value and expressed as an Environmental Load Unit (ELU). For instance, 1 g of copper has 10 ELU/kg, aluminum 15 ELU/kg, and methane 2 ELU/kg, etc. (note that the ELU values are made up here for illustrative purpose). Thus, weighted impact of a product can be readily calculated from the life cycle inventory results.

The target method relates relative significance or weight to some sort of target of impact category. Distance between current impact level and future target impact level becomes the weight of the impact category. Multiplication of the weight and normalized impact of an impact category yields the weighted impact of that impact category. Summing up over all the impact categories conveys the weighted impact of a product (Lee and Inaba, 2004).

In all practical consideration, we recommend using the panel method to determine the weighting factor. This is because the panel method is easy to understand and the simplest of all the weighting methods, while generating weighting factors with reasonable degree of scientific background. If more sophisticated weighing method is desired, both the target method and the monetization method can be used.

The panel method was used for the calculation of the weighted impact of the water kettle. The weight of the impact categories of GW, AD, EU, POC and ARD were 0.29, 0.16, 0.14, 0.13, and 0.28, respectively. These values originated from an electronics company in Far East Asia. One should be cautioned that these numbers reflect value judgment of a certain group of people; thus, these values are only meaningful to those who developed it, and shall not be applied to your own case. We advise you to develop your own weight based on the panel method described here.

Table 30 shows normalized and weighted impact of each impact category. The most dominant impact category of the water kettle is global warming followed by abiotic resource depletion and then acidification. This indicates that global warming, abiotic resource depletion, and acidification are the three most significant impacts on the environment caused by the water kettle. This happens to be the same conclusion reached under the normalized impact case, although the order of significance between abiotic resource depletion and acidification changed from normalized impact to weighted impact.

Next the weighted impact per life cycle stage is shown in Table 31. The results in this table demonstrate that the most dominant life cycle stage of the water kettle is the product use stage followed by the use of raw materials stage. This indicates that significant environmental impact occurs mostly during the product use and to less

Table 30 Weighted impact of the water kettle per impact category.

Impact category	*Normalized impact (millionth pe-yr/ water kettle)*	*Weight*	*Weighted impact (millionth pe-yr/ water kettle)*	*Fraction (%)*
GW	7018.70	0.29	2035.42	65.76
AD	2792.90	0.16	446.86	14.44
EU	80.90	0.14	11.33	0.37
POC	320.27	0.13	41.64	1.35
ARD	1998.94	0.28	559.70	18.08
Total			3094.95	100.00

Table 31 Weighted impact of the water kettle per life cycle stage (unit: millionth pe-yr/water kettle).

Impact category	*Use of raw materials*	*Manufacture*	*Distribution*	*Product use*	*End of life*	*Total*
GW	76.03	54.02	12.37	1898.92	−5.92	2035.42
AD	24.73	11.32		410.50	0.31	446.86
EU	11.17				0.16	11.33
POC	33.73	0.00	0.70	7.03	0.18	41.64
ARD	242.37	10.68	27.25	312.64	−33.24	559.70
Total	388.03	76.02	40.32	2629.09	−38.51	3094.95

extent during the extraction of resources and processing them to the materials for the manufacturing of the water kettle. Thus, key issues for product improvement should be obtained mainly from the product use stage, and then from the use of raw materials stage.

In the life cycle interpretation where key issues are identified, weighted impact results are also used for the identification of key issues. Since weighted impact is derived from all the impact categories combined, the identified key issues differ from those in the characterized impact. However, key issues from the weighted impact reflect the entire product's perspective. Therefore, it is recommended that key issues be identified both from the characterized impacts and from the weighted impacts of a product, if possible, and those key issues identified from both approaches are chosen as the final key issues of the product. Details about the weighted impact of the water kettle are shown in section 3.6.

2.4.3 Evaluation of reliability of the LCA results

Implementation of LCA is based on basic premises including assumptions, data quality, and methodologies employed. In order to evaluate the validity of these premises, one needs to perform completeness check, sensitivity check, and consistency check.

Completeness check

The objective of completeness check is to evaluate whether data used for LCA are complete. The results of the completeness check of the water kettle LCA results are shown in Table 32. It lists all unit processes identified in the process tree from the use of raw materials stage to the end of life stage.

Table 32 Completeness check result of the water kettle.

Unit process	*Complete?*	*Action required?*
PP production	A	
Housing	B	Check inventory
Stainless steel production	A	
Heater manufacturing	B	Check inventory
Cardboard production	A	
Packaging	B	Check inventory
Electricity	A	
Manufacture	A	
Distribution	C	Check inventory
Product use	B	Check inventory
Incineration	C	Check inventory
Landfill	C	Check inventory
Recycling	C	Check inventory

(Note: A represents 100% and E 0% completeness, all qualitative)

Sensitivity check

Allocation methods used, uncertainties in input data, and assumptions made are evaluated to ensure reliability of the LCA results. Sensitivity can be expressed as the percentage of change or as the absolute deviation from the results. In general, a change in the result greater than 10% is considered significant (ISO 14043, 2000). Often times the use of a scenario (e.g., data range, assumption range, best and worst case) is envisaged the most useful method in performing the sensitivity analysis.

The sensitivity check of the allocation method applied for the water kettle LCA was made. The check evaluated two different allocation criteria, one is economic and the other mass. Allocation was made for the electricity consumed for the manufacturing of water kettles in the same factory, Model A and B. The weighted impact of the water kettle based on economic criteria was 3094 millionth pe-yr. When allocation was made based on mass basis, the weighted impact was 3123 millionth pe-yr. The difference in weighted impact between two different allocation criteria is divided by the weighted impact of the water kettle based on the original allocation criteria, and the percent difference or sensitivity was computed less than 1% as shown in Table 33. Thus, it is judged that the allocation method used is not sensitive to the LCA results.

Table 33 Sensitivity check result of the water kettle for the allocation method.

Allocation criteria	*Weighted impact (unit: millionth pe-yr/water kettle)*
Economic criteria	3094.95
Mass criteria	3123.41
Sensitivity (%)	0.92

Consistency check

Whether LCA methods, procedures and assumptions are applied consistently throughout the entire LCA is the objective of the consistency check. Questions to address here are:

- Whether the allocation rules and decision rules for mass inclusion were applied consistently to all unit processes and sub systems,
- Whether characterization factors and life cycle impact assessment methods were applied consistently.

The result of the consistency check for the water kettle LCA results is shown in Table 34, demonstrating that consistency of the data source, accuracy, etc. meet the requirements set in the scope definition phase. Thus, no actions were taken.

Table 34 Consistency check result of the water kettle.

Item	*Check*		*Action required?*
Data source	Database	OK	No action
Data accuracy	Good	OK	No action
Database age	5 years	OK	No action
Characterization factor	OK		No action
Characterization method	OK		No action

Data quality requirements

Collected data must be checked with respect to the type of the data, collected or literature data, of which requirements were stipulated in the data quality requirement. If the data collected does not meet the requirements, either recollect the data or modify the data quality requirements. Thus, the data collection can be an iterative process. In addition, the data must also be checked against the temporal, geographical and technological boundaries in terms of meeting the requirements set at the onset of the data collection.

2.4.4 Report of the LCA results

Conclusions drawn from the LCA study as well as recommendations made are reported in any LCA study. Main items in the conclusion part are key issues identified. Recommendation section typically addresses actions to take from the LCA results. Key issues and conclusions drawn from the water kettle LCA are described in section 3.6.

2.5 Summary

Life Cycle Assessment is a robust analytical tool for the assessment of environmental aspects of a product throughout its entire life cycle. Because of its robustness the implementation of LCA often takes longer time and requires much effort. In the light of the rapidly changing market conditions, where new products are introduced at a record pace, quick and robust assessment of environmental aspects of a product is an indispensable part of ECODESIGN and environmental communication of the product. As such, the implementation of LCA must generate reliable results in the shortest possible time.

Of the four phases in LCA, the goal and scope definition phase determines the direction, breadth and depth of the remaining three other phases of LCA. This in turn dictates time and effort required for implementing LCA as well as credibility of the LCA results. The key elements for the practical approach in LCA are summarized below.

- Goal definition: Clearly identify who are the target audiences and what are the applications of the LCA results.
- System boundary (product system) setting: Apply decision rule for mass inclusion realistically. Always consider trade off between the goal of the LCA study and the decision rule for inclusion.
- Data collection: Use database as much as possible. Build your own database for processes and specific materials related to your products. For general materials and data such as energy, transport and disposal, high quality databases must be secured and used.

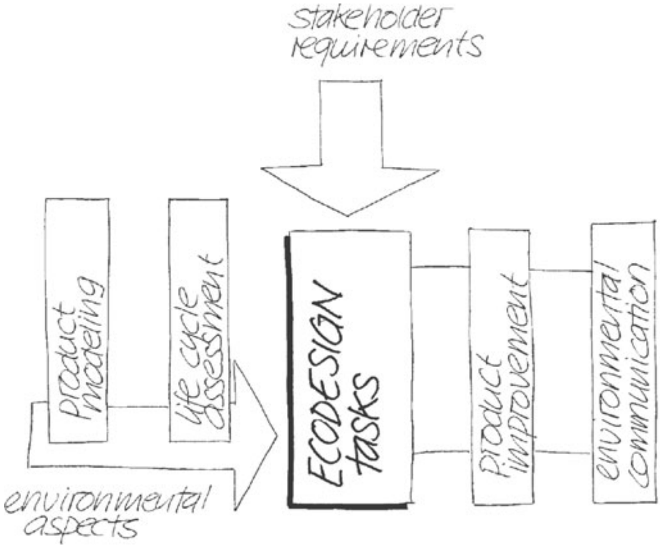
The water kettle example shows not only the step-by-step implementation of LCA but also how to generate significant issues and environmental profile of the water kettle. The significant issues were identified based on the characterized impact, and the environmental profile based on the inventory and characterized impact results.

The basic concept of LCA, its four phases, logics behind the inventory computation, science behind the environmental impact, method for quantifying impact, identifying key issues as well as evaluating the LCA results were delineated in this chapter.

The example in conjunction with the step-by-step procedure was designed to be practical for daily use of LCA in the industry for product development and environmental communication of the product. Although the LCA method in this chapter is practical and easy to implement, it does not mean that the method here is not robust. In principle, the LCA method in this book follows ISO 14040 series on LCA. Application of the LCA results for ECODESIGN is discussed in section 3.6, and application to Environmental Product Declaration is dealt with in chapter 5.

Chapter 3

ECODESIGN TASKS



A successful ECODESIGN process requires combining significant environmental aspects and stakeholder requirements. Chapter 3 demonstrates how to derive ECODESIGN tasks from both perspectives.

Environmental Quality Function Deployment (EQFD) is used to translate stakeholder requirements into important environmental parameters. Environmental Benchmarking (EBM) with competitor's products is also applied to obtain additional environmental parameters to redesign the product.

The significant environmental aspects are covered in two ways: with and without Life Cycle Assessment (LCA). First the ECODESIGN PILOT's Assistant is used for identifying ECODESIGN improvement strategies and then the LCA results from chapter 2 are interpreted to derive key issues for product improvement.

Finally, the checklists of the ECODESIGN PILOT are applied to derive ECODESIGN tasks for product improvement. At the end of this chapter a list of ECODESIGN tasks to implement for an improved water kettle can be expected.

3.1 Introduction

After describing the product with a quantified model (chapter 1) and performing an environmental assessment (chapter 2) the essential question is now how to derive ECODESIGN tasks for product improvement. Finding appropriate ECODESIGN tasks for product improvement is the objective of this chapter.

Assuming you know the environmental weak points of your product, assuming you know what your customers are expecting from your product: How would you proceed to develop an improved product?

First of all, we obviously have to work with two perspectives simultaneously – one is the environmental aspect and the other could be named as the "stakeholder" requirements. The so-called stakeholders could be your customers, the society in the form of laws, regulations, directives or standards and of course your competitors on the market. All these stakeholders are demanding requirements from your product. Therefore, we have to develop a good understanding about who the stakeholders are and what exactly their requirements are.

There is of course a broad spectrum of such stakeholder requirements. If we are looking at products developed these days we find technical artifacts meeting safety-, reliability-, quality-, manufacturing-, cost-, etc. requirements. Engineers consider many aspects surrounding the products life. Most of the time this is done in an excellent way and the products resulting are sometimes high tech products offering a broad functionality with high quality and reasonable price.

The only aspect often missing is a well thought through environmental concept that is followed from the beginning on and results in a product that meets even strict environmental requirements. The knowledge and experience of integrating environmental aspects is often missing – even in large companies.

Focusing on environmental issues we can see that combining the stakeholder and environmental perspectives brings us right to the leading question of this chapter:

- Who are the stakeholders and how to fulfill the stakeholder requirements?
- What are the significant environment aspects and how to fulfill environmental requirements?
- How to derive ECODESIGN tasks for product improvement?

This chapter aims therefore at identifying and integrating environmental requirements into the (re)design process of a product. How the stakeholder and environmental perspective can be linked together and addressed in a systematic way will be described in this chapter.

First, stakeholder requirements are identified (section 3.2) and then translated into the environmental parameter developed in chapter 1. Environmental Quality Function Deployment (EQFD) is explained in section 3.3. EQFD links stakeholder requirements to the environmental parameter. In section 3.4 Environmental Benchmarking (EBM) is used for comparison with competitor's products on the market to pointing out strengths and weaknesses of the own product. To evaluate the environmental performance of the product two principal ways are shown here, the one without Life Cycle Assessment (LCA) (section 3.5) and the other using the LCA results calculated in chapter 2. An interpretation of these results is done in section 3.6. In order to

achieve an environmental evaluation without performing an LCA a new tool: The ECODESIGN PILOT's Assistant – a web-based tool to derive appropriate ECODESIGN improvement strategies – will be introduced. At the end of this chapter, both perspectives (stakeholder requirements and significant environment aspects) are brought together and redesign tasks are worked out using the ECODESIGN PILOT (Wimmer and Züst, 2002) for deriving improvement strategies and to identify ECODESIGN measures using the PILOT's checklists (section 3.7).

This chapter starts with finding new solutions to achieve an improved product (continued in chapter 4). With the redesign tasks specified in this chapter we can assure to meet customer expectations, to fulfill legal compliance, to achieve competitive advantages and to improve environmental weak points of a product.

Figure 16 displays an overview of the methodical elements used to derive ECODESIGN tasks.

Throughout the whole chapter, again the example water kettle is used to give guidance for deriving ECODESIGN tasks for improving a predecessor model of the water kettle. All steps necessary to do that are demonstrated here. At the end of this chapter, systematically developed ECODESIGN tasks for product improvement of the water kettle can be expected.

The procedure described in this chapter should be easy to follow in order to motivate the reader to perform a similar analysis for his/her own product.

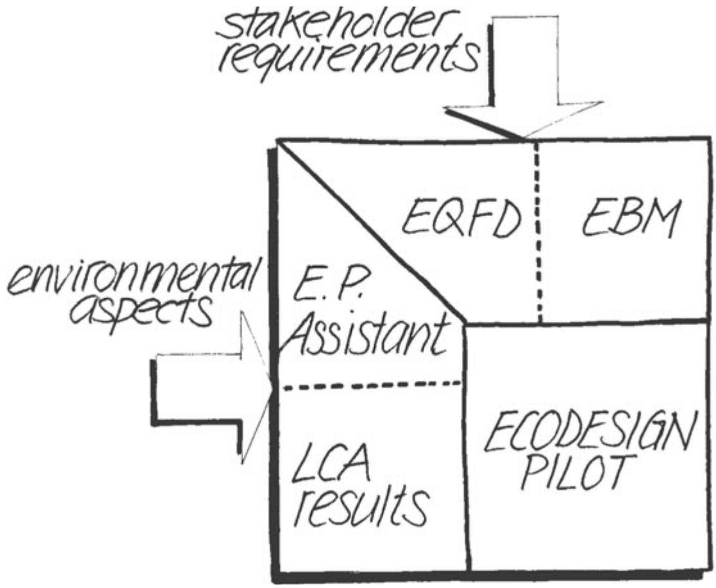
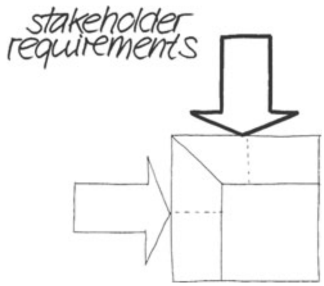


Figure 16 Methodical elements to derive ECODESIGN tasks.

3.2 Stakeholder requirements



Redesigning a product requires to identify possible stakeholders first. The question is: Who are the potential stakeholders and what kinds of environmental requirements (or expectations) do they have?

Looking at an electrical product like a water kettle, apart from customers expectations we have to consider environmental directives among others the new European directive on Waste of Electrical and Electronic Equipment (WEEE, 2003) requiring Design for Recycling to comply with. Additionally, we have to consider the requirements from voluntary agreements like eco-labels. Nevertheless, comparison with other water kettles on the market has to be done as well. This might yield other design requirements to meet in order to come up with a competitive environmentally sound product.

3.2.1 Type of stakeholders

Obviously those who are actually using the product (end user) are considered first and are clearly perceived as stakeholder. In addition to the end user, we can also see business-to-business customers as stakeholder, which might have different environmental requirements. However, there are more stakeholders setting requirements to products a company has to be aware of. Most important is the mandatory requirements like environmental directives and regulations (e.g. Restriction of Hazardous Substances directive). Additionally voluntary instruments, such as product specific requirements from Eco-labels (e.g. Nordic Swan) or standards and Technical Reports, shall be named e.g. Technical Report on integrating environmental aspects into product design and development (ISO/TR 14062, 2002).

In the following possible stakeholder groups and their type of requirements, which have to be fulfilled by the product are listed:

- End user requirements (individual demands to achieve customer satisfaction)
- B2B customer requirements (demands to achieve competitive advantage)
- Environmental directives and regulations (mandatory requirements to fulfill legislation)
- Eco-labels (voluntary product criteria to achieve certification)
- Standards (general/procedural requirements to fulfill)
- Competitors (environmental design parameter or feature to compete with)

For different products there are different directives and regulations available. In addition, eco-labels differentiate in various product criteria. For some product categories these criteria are set up for a long period due to common interest (e.g. the German Blue Angle started in 1979). For those we can find even detailed design requirements to follow. For other products no specific design criteria are set up yet or are just under development.

Since it is difficult to describe detailed design requirements from the various types of stakeholder in general, the product example water kettle shall be used to explain the stakeholder requirements in the following chapters; no ranking shall be expressed here.

3.2.2 End user requirements

End user demands are usually closely linked to the use stage of a product. Products characteristics like lifetime, usability, etc. are addressed. Concerning the water kettle, we can see the fast and quick heating or boiling of water as a main customer demand. Compared to the other forms of heating established in regular household appliances (e.g. oven) the water kettle has its advantage in the short boiling time but also in the availability in different places others than a kitchen (e.g. offices). Together with a broad offer of instant food, that is prepared with hot water, only a water kettle can be an important device for preparing quick meals. To do so this requires the possibility to move “freely” within the kitchen or office with the water kettle. Therefore, the jar of the water kettle should be separable from the electrical installation required. *Requirement: easy to use*

Generally it is understood from the end user that the short time for boiling water in a water kettle is causing only low energy loss while boiling water (this issue will be discussed in detail later). Energy efficiency is therefore another environmental requirement consumers might have. *Requirement: energy saving*

3.2.3 B2B customer requirements

Although a water kettle is a typical end user product, B2B customers could be wholesalers but also institutions responsible for public procurement. Their orders are large in number and some additional requirements can apply here. Assuming a large institution is equipping its offices with small kitchens among other items with water kettles, then this institution might have some purchasing criteria, in line with the companies policy, making sure products purchased are generally not harmful to the environment. *Requirement: environmentally safe*

Additionally, one can imagine such criteria could also refer to extended lifetime and durability of the product. *Requirement: durable*

3.2.4 Requirements from environmental directives and regulations

There are several directives and laws available worldwide concerning environmental regulations. This book focuses on the "most popular ones", which are the Waste of Electrical and Electronic Equipment (WEEE), the Restriction of Hazardous Substances (RoHS) and the upcoming Energy using Product (EuP) directive, currently under development.

Waste of Electrical and Electronic Equipment – WEEE

The European WEEE directive 2002/96/EC has been introduced because of the growing amount of such waste within the Community. On top of that, recycling of this waste is not undertaken to a sufficient extent and the content of hazardous components in electrical and electronic equipment is a major concern within the European Union.

The WEEE directive is aiming therefore to prevent, reduce, reuse, recycle and recover waste of electrical and electronic equipment. The directive became law in February 2003. Member states must implement by August 2004 and shall encourage design and production to facilitate dismantling, recovery, reuse and recycling from waste of electrical and electronic equipment.

Furthermore member states shall ensure that such waste returned from households free of charge, including distributors take back. Waste collected is transferred to authorized collection facilities to achieve a minimum rate of separate collection of 4 kg per inhabitant and per year from private households. This applies to the following ten categories of equipment:

- Large household appliances
- Small household appliances
- IT and telecommunication equipment
- Consumer equipment
- Lighting equipment
- Electrical and electronic tools
- Toys, leisure and sports equipment
- Medical devices
- Monitoring and control instruments
- Automatic dispensers

According to the WEEE directive Annex I B, the water kettle is classified as a small household appliance and therefore the rate of reuse and recycling has to be in minimum 50% and the rate of recovery has to be in minimum 70% – both by average weight. *Requirement: easy to recycle; Requirement: easy to reuse*

Among other aspects the WEEE directive also requires to remove problematic components before recycling. These components are for instance:

- polychlorinated biphenyls (PCB)
- mercury containing components, such as switches or backlighting lamps
- batteries
- printed circuit boards of mobile phones generally
- toner cartridges, liquid and pasty, as well as colour toner
- plastic containing brominated flame retardants
- asbestos waste and components which contain asbestos
- cathode ray tubes
- hydro/chloro/fluoro/carbons CFC, HCFC, HFC, HC
- gas discharge lamps
- liquid crystal displays and all those back-lighted with gas discharge lamps
- external electric cables
- and others …

This indicates a clear demand for a product structure which allows easy disassembling of products and or providing for easy extraction of harmful substances. *Requirement: easy to disassemble*

Restriction of Hazardous Substances – RoHS

The European RoHS Directive 2002/95/EC is aiming at the elimination respectively at the reduction of certain hazardous substances in the production, treatment and disposal of electrical and electronic equipment. The directive became law in February 2003 and must be implemented by the member states by August 2004. From July 2006 on new electrical and electronic equipment put on the European market shall not contain: lead, mercury, cadmium, hexavalent chromium as well as flame retardants like polybrominated byphenyls (PBB) and polybrominated dyphenyl ethers (PDBE). *Requirement: free of hazardous substances*

Energy using Product – EuP

The European EuP directive (EuP, 2004), currently under development, tries to establish a framework for setting ECODESIGN requirements for energy-using products to support the integration of environmental aspects in product design and development.

The EuP directive defines an energy-using product as a product, “which is dependent on energy input (electricity, fossil and renewable fuels) to work as intended and a product for the generation, transfer and measurement of such energy, including parts which are intended to be incorporated into EuP which are placed on the market as individual parts for end-users, the environmental performance of which can be assessed independently.” The directive is not applying to means of transport for persons or goods by inland, sea and air.

Products complying with these ECODESIGN requirements, stipulated in implementing measures should bear the "CE" marking and associated information, in order to enable them to be put on the market. *Requirement: energy saving; Requirement: other product specific requirements to be developed in the future*

3.2.5 Requirements from eco-labels

Many different eco-label schemes exist worldwide. You probably have seen one of the logos in Table 35 on one or the other consumer product you purchased. But do you know what is actually behind these logos? What does it mean if a product carries these symbols? Well, of course it is highlighting its environmental benefits, but what exactly is it?

Table 35 Eco-labels.

EU Flower	*Nordic Swan*	*Blue Angel*	*Eco Mark*
www.eco-label.com	www.svanen.nu	www.blauer-engel.de	www.ecomark.jp

ISO 14020 series subdivides environmental communication into three different types. Type I describes eco-label schemes, type II self declared environmental claims and type III an Environmental Product Declaration (see chapter 5). The eco-label schemes that should be discussed here are those following ISO 14024, type I. Well-known labels out of this group are among others:

Nordic Swan	Denmark, Finland, Iceland, Norway, Sweden
Blue Angel	Germany
NF environment	France
EU Flower	Europe
Environmental Choice	Canada
Eco Mark	Japan

For discussing design requirements for the water kettle, the Nordic Swan will be used here as an example, since this eco-label scheme provides product specific requirements explicitly for a water kettle and lists "design criteria for kitchen appliances" in general.

Nordic Swan – design criteria for kitchen appliances

To obtain the Nordic Swan eco-label for kitchen appliances (Nordic Eco-labeling, 2002), products must have a modular design, whereby a module is referring to a part of a product that can be separated from the product. The modules must be designed

in a way that makes it possible to reuse the module in common recycling systems when separated from the product. A modular structure shall be realized to facilitate disassembly and repair of the product.

Furthermore, the following design requirements must be fulfilled according to Nordic Swan for kitchen appliances in general (Nordic Eco-labeling, 2002):

- Modules must be separable and reassembled without difficulty.
- Points of attachment/disassembly points must be easily accessible with tools.
- The connections between different materials must be easy to locate.
- No permanent bonds in the form of glue or welding between different types of materials must be used.
- Housings may contain a maximum of four different types of plastic or plastic alloys, and these must all be separable from one another.
- Plastic parts (>25 g) must be capable of identification.
- Plastic parts must not be painted or varnished in any way that might reduce the reusability of the material.
- Labels/tabs/stickers must be made of the same material as the components to which they are attached.
- The use of chlorinated plastics is not permitted.
- No halogenated flame-retardants may be added to plastic parts.
- Cadmium, lead and mercury compounds must not be added to plastic parts.
- A number of phthalates must not be present in the product (dicylohexy phthalates, diisobutyl phthalates, dibutyl phthalates, …).
- Cadmium, lead, hexavalent chromium and mercury compounds may not be added (following the RoHS directive). The requirement also covers soldering paste.
- Packaging must not contain chlorinated plastic.
- The product must be designed and labeled so it is possible to identify, separate and recycle the components and modules in accordance with the WEEE-directive.

In particular Nordic Swan demands the following design requirements for a water kettle:

- must be equipped with an auto-off function
- must not use more than 110 Wh/liter to boil water (min. 99°C)
- must include instructions on the method for and frequency of descaling

This leads to environmental requirements like:

Requirement: free of hazardous substances
Requirement: easy to repair
Requirement: easy to recycle
Requirement: easy to disassemble
Requirement: easy to reuse
Requirement: energy saving
Requirement: easy to maintain

3.2.6 General requirements from standards

Of the ISO 14000 series standards, the Technical Report ISO TR 14062 (2002) is currently the only document describing the integration of environmental aspects into the product design and development process. Within this document product life cycle considerations, environmental impacts and the product development process are linked and strategic, management and product considerations are addressed.

According to ISO TR 14062 (2002) the integration of environmental aspects into product design and development involves setting strategic product related objectives for reducing the product's environmental impact while maintaining or improving its functionality. Two such objectives are:

(1) Conservation of resources, recycling and energy recovery via optimizing the use of resources required for the product (like materials and energy) without having any adverse effect on its performance, durability, etc. decreasing the quantity of hazardous materials and reduce the creation of waste during manufacturing and disposal, achieving suitability for reuse, recycling and for use as source of energy.

(2) Preventing of pollution, waste and other impacts through dealing with problems at their sources.

The product related issues are observed in:

- integrating environmental aspects early in the design and development process
- analyzing whole product life cycle
- focusing on functionality – how well the product suits the intended purpose (usability, useful lifetime, …)
- considering all relevant impacts and aspects (multi-criteria)
- dealing with trade-offs, seek for optimal solution

ISO TR 14062 (2002) outlines general design approaches, which are instrumental in generating design options. These approaches can be:

- improvement of material efficiency: low impact materials, renewables, recycling
- improvement of energy efficiency: energy consumption, renewable sources
- sparing use of land
- design for cleaner production and use: apply cleaner production techniques, avoid hazardous consumables
- design for durability, reparability, maintainability
- design for optimizing functionality (multiple functions), modularity
- design for reuse (of components), recycling, disassembly
- avoidance of hazardous substances in the product
- …

Although ISO TR 14062 (2002) is not intending to give any detailed design guidelines, or guidelines at all, it clearly indicates the idea behind outlining design approaches to foster design ideas. Therefore the document can be used for completing the stakeholder requirements.

3.2.7 Summarizing stakeholder requirements

Listing what we found for the water kettle and adding missing requirements we can generate a generic list of general environmental stakeholder requirements in Table 36.

Table 36 List of environmental stakeholder requirements.

environmentally safe
free of hazardous substances
lightweight
durable
less transportation
energy saving
easy to use
easy to maintain
easy to repair
easy to recycle
easy to disassemble
easy to reuse

3.3 Environmental Quality Function Deployment

With Environmental Quality Function Deployment the stakeholder requirements are linked to the environmental parameter such as weight, lifetime, materials used, rate of recyclability, etc. The idea is to identify those parameters, which are important for meeting the stakeholder requirements.

Normally there are no detailed design requirements coming from different stakeholders therefore it is difficult to translate them into product development (e.g. what does it mean to realize the requirement "easy to use"?). Obviously methodical support is needed here. Therefore, a modified version of Quality Function Deployment (QFD) (Akao, 1990) shall be used. QFD asks first for customer demands and links them later within the House of Quality to technical design parameter. From this technical design parameters detailed design requirements can be derived. The same idea

shall be applied with the Environmental QFD (EQFD) following Wimmer et al., 2003. The stakeholder requirements will be translated into the environmental parameters developed earlier in chapter 1 (see Figure 17).

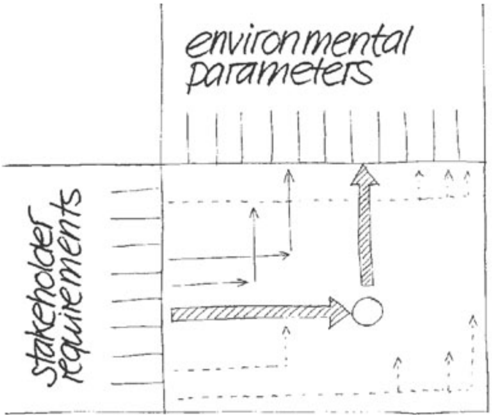


Figure 17 EQFD approach linking stakeholder requirements to environmental parameters.

By doing so, important environmental parameters can be identified from the stakeholder requirements. Once the important environmental parameters are identified, ECODESIGN PILOT's improvement strategies will be assigned to them.

The stakeholder requirements in Table 36 are formulated in generic terms and therefore applicable to all kinds of products, but it is obvious that not all of the above listed requirements are equally important for any specific product.

Let us do the following weighting example and express the different importance for different products with weighting factors.

For the weighting factor a scale from 0–10 is recommended, we assign the value 0 to indicate that a stakeholder requirement is not important at all. The value 10 is assigned to express highest importance; any value in between is possible for expressing importance. In Table 37 the different weighting factors are expressed for a wooden table, a washing machine and the water kettle. In addition, justification for the water kettles importance is presented.

It is easy to understand that the importance for a wooden table is an environmentally safe product, regarding emissions (vapor) during use, whereby a washing machine should be energy saving, easy to recycle and reuse, therefore easy to disassemble and should contain no hazardous substances (following WEEE and RoHS).

Since the weighting of the environmental requirements from stakeholders has been done (for every product this weighting might look different), the next step is to define the relationship matrix between the stakeholder requirements and the environmental parameter. This is shown in Table 38. The environmental requirements and their weighting factors from Table 37 and the environmental parameters are correlated using a relationship matrix. Relationship factors express either a weak

Table 37 Weighting of environmental stakeholder requirements.

Environmental stakeholder requirements	*Weight*			
	Wooden table	*Washing machine*	*Water kettle*	*Justification for the water kettle's weight*
environmentally safe	10	0	0	no emissions during use expected
free of hazardous substances	10	10	10	important due to RoHS
lightweight	5	3	0	not important
durable	10	7	5	less important – but relevant for B2B
less transportation	3	3	0	not important
energy saving	0	10	10	important for end user and eco-label
easy to use	0	5	10	important – relevant for end user
easy to maintain	3	7	5	less important – but connected with energy consumption
easy to repair	3	7	0	not important
easy to recycle	0	10	10	important due to WEEE
easy to disassemble	0	10	5	less important – but relevant for eco label
easy to reuse	0	7	0	not important

relationship (1), a medium relationship (3) or a strong relationship (9). For each column (environmental parameter) the weight (stakeholder importance) is multiplied by the relationship factor and summed up for every environmental parameter. As a result, a relative importance is expressed at the last row of Table 38. From that result important environmental parameters for the water kettle can be identified as:

- Materials used (Importance: 13%)
- Rate of recyclability (Importance: 13%)
- Problematic materials (Importance: 9%)

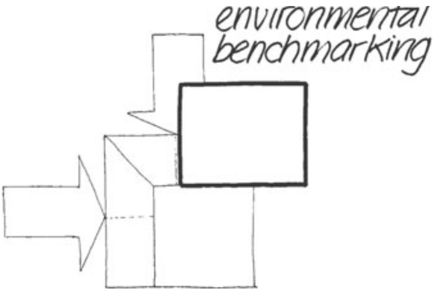
Having a generic relationship matrix valid for all kinds of products is not possible, since every product has its own relation between environmental stakeholder requirements and environmental parameter. Nevertheless, possible (obvious) environmental relations can be detected in the highlighted matrix fields in Table 38.

Table 38 Translation of environmental stakeholder requirements into environmental parameters with EQFD.

Environmental stakeholder requirements / Environmental parameters	Customer importance	weight	volume	supply parts env. performance	lifetime	functionality	materials used	problematic materials	production technology	production waste	packaging	transportation	usability	energy consumption	waste (generated)	noise and vibrations	emissions	maintenance	reparability	fasteners and joints	time for disassembly	rate of reusability	rate of recyclability
Direction of improvement		↓	↓	↑	↑	↑	↓	↓	↓	↓	↓	↓	↑	↓	↓	↓	↓	↓	↑	↓	↓	↑	↑
Units		kg	m^3		h				kWh	kg	kg	km		kWh	kg	dB					h	%	%
environmentally safe	0							9	9						9		9						
free of hazardous substances	10			3			9	9			9												9
lightweight	0	9					9				3		3										3
durable	5	3		3	9								3					3	3				
less transportation	0		3	3							3	9											
energy saving	10					3								9									
easy to use	10	3	3			3							9			9							
easy to maintain	5																	9		1			
easy to repair	0			3	3														9	3	3	1	
easy to recycle	10						9	3		9													9
easy to disassemble	5			3																9	9	9	
easy to reuse	0			9	3																9	9	
Importance (relative %)		3	2	4	3	4	13	9	0	6	6	0	8	6	0	6	0	4	1	4	3	3	13

9 ... strong relationship
3 ... medium relationship
1 ... weak relationship

3.4 Environmental benchmarking



The environmental performance of competitor products on the market has to be considered as well in the ECODESIGN process. Assuming your competitor claims as competitive advantage the environmental performance of his product – how would you react? How would you find out about the environmental strengths and weaknesses of your product over the competitors products?

The next thing to do is deriving redesign options by analyzing the competitor's products.

All products described here are fictitious products. Any similarity with products on the market is unwanted and purely coincidental. The products attributes are assigned only for the sake of explanation and demonstration of the approach presented in this book.

The current water kettle is the one shown in Figure 18. This one shall be redesigned. It consists of a housing with a lid and a handle all made from PP, a switch unit made from PA6 and a heater made of stainless steel. The power supply is provided via a directly connected regular copper cable. The product is equipped with an automatic switch, which switches off the water kettle once the water is boiling. A detailed product description was already given in chapter 1.

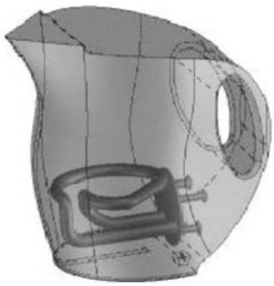


Figure 18 Current water kettle.

The competitor product A is shown in Figure 19. It has an appealing design, consisting of stainless steel housing and a PA6 handle. The product consists of two parts the housing and a ground plate (from PA6). The ground plate carries the power cable and the electrical contacts to the actual kettle. By that, the water kettle itself can be disconnected and moved freely. This feature makes this product an easy to use appliance. The product is also equipped with an automatic switch off function.

Figure 19 Competitor product A.

The competitor product B is shown in Figure 20. With this product a similar version to our own product has been chosen for benchmarking. This product represents modern design and consists of a housing and handle made from PP. The lid is made of PVC. The power cable is connected directly with the kettle. The product is equipped with an automatic switch off function.

Figure 20 Competitor product B.

First in environmental benchmarking is gathering data of the products to be compared. This should be done by investigating or measuring especially when it concerns design determinant data. This is why actual disassembly of every product is recommended in order to determine materials, weights and structure of the product. But also the electrical energy consumption, required to perform its intended function shall be measured from each product before starting the benchmarking (see Figure 21).

Once the data are available, they can be prepared for benchmarking. Benchmarking shall be done against the environmental parameter developed in chapter 1. Table 39 presents an overview of the different performances of competitor product A and B as well as of our own product.

Figure 21 Measuring the actual energy consumption.

Table 39 Benchmarking with environmental parameter.

Environmental parameters	*Own product*	*Competitor product A*	*Competitor product B*
Weight	0.67 kg	1.2 kg	0.8 kg
Volume	1 liter	1 liter	1 liter
Supply parts environmental performance	supply parts: heater, cable	supply parts: heater, cable	supply parts: heater, cable
Lifetime	3 years	5 years	3 years
Functionality	heat and boil water, automatic switch off	heat and boil water, automatic switch off	heat and boil water, automatic switch off
Materials used	PP, PA, …	stainless steel, PA, …	PP, PA, PVC …
Problematic materials	PVC in cable	none	PVC in product and cable
Production technology	injection molding	metal forming	injection molding
Production waste	none	sheet metal	none
Packaging	200 g cardboard	300 g cardboard	250 g cardboard, 50 g PVC
Transportation	3000 km	2000 km	2500 km
Usability	no flexibility due to attached cable	free movement of kettle due to external ground plate	no flexibility due to attached cable
Energy consumption	109 Wh per liter	112 Wh per liter	104 Wh per liter
Waste (generated)	–	–	–
Noise and vibrations	low	low	low
Emissions	–	–	–
Maintenance	descaling required	descaling required	descaling required
Reparability	not possible	possible	not possible
Fasteners and joints	snap fit and screws	screws	snap fit and screws
Time for disassembly	not possible	2 min	not possible
Rate of reusability	no reuse possible	no reuse possible	no reuse possible
Rate of recyclability	50%	80%	40%

The different performance is now evaluated with numbers ranking from:

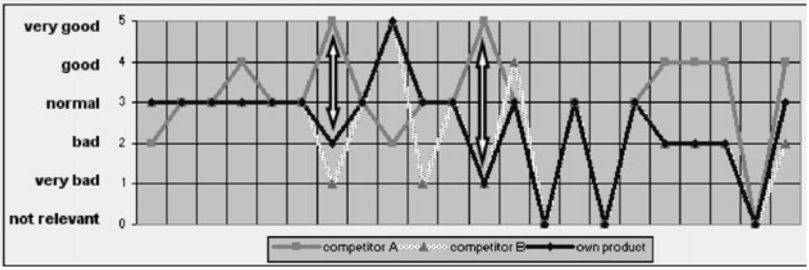
very good: 5
good: 4
average: 3
bad: 2
very bad: 1

If there is an environmental parameter not relevant for the product (e.g. emissions during use) the value 0 is assigned.

When ranking was applied to the environmental parameters of the three products, the actual performance of the benchmarked products can be expressed as shown in Table 40.

Table 40 Identifying environmental parameter with EBM.

Environmental parameter 5.. very good 1.. very bad 0.. not relevant	weight	volume	supply parts env. performance	lifetime	functionality	materials used	problematic materials	production technology	production waste	packaging	transportation	usability	energy consumption	waste (generated)	noise and vibrations	emissions	maintenance	reparability	fasteners and joints	time for disassembly	rate of reusability	rate of recyclability
Importance (%)	3	2	4	3	4	13	9	0	6	6	0	8	6	0	6	0	4	1	4	3	3	13
own product	3	3	3	3	3	3	2	3	5	3	3	1	3	0	3	0	3	2	2	2	0	3
competitor A	2	3	3	4	3	3	5	3	2	3	3	5	3	0	3	0	3	4	4	4	0	4
competitor B	3	3	3	3	3	3	1	3	5	1	3	1	4	0	3	0	3	2	2	2	0	2



Compared to our own product we can see a better performance of product A in *lifetime, problematic materials, usability, reparability, fasteners and joints, time for disassembly* and *recyclability*. Product B is only doing better in *energy consumption*.

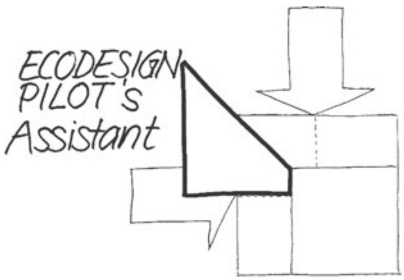
Considering the difference in performance (biggest gaps in Table 40) and the importance of the environmental parameters, the resulting environmental parameters from EBM are:

- Problematic materials: high performance by the competitor product A and high importance of environmental parameter (9%)
- Usability: high performance by the competitor product A and high importance of environmental parameter (8%)

All other environmental parameters do have a lower gap or a lower relative importance and are therefore not considered here.

At this point, the stakeholder requirements are clearly determined, a good understanding has been developed about what customers are expecting, what legal compliance requires and what has to be done to compete against the competitors products.

3.5 Environmental aspects with the ECODESIGN PILOT's Assistant



The main idea of the ECODESIGN PILOT's Assistant is to support product development in finding ECODESIGN strategies quickly and consequently ECODESIGN (re)design tasks for product improvement. The ECODESIGN PILOT's Assistant has been developed at the Vienna University of Technology by the ECODESIGN research group at the Institute for Engineering Design.

The ECODESIGN PILOT's Assistant is available under www.ecodesign.at/assist and helps to identify ECODESIGN improvement strategies for products. The Assistant is a kind of expert system that asks questions along the product life cycle, calculates from the answers given possible scenarios of the products' life cycle and advises improvement strategies accordingly. In six forms data are questioned about the product life cycle and significant environmental aspects are found applying a set of rules and if-then logics to the answers given. As a result, the Assistant indicates possible ECODESIGN improvement strategies for an analyzed product. The tool has been tested with various products and works quite well. The results presented are directly linked to the ECODESIGN PILOT and its checklists.

The ECODESIGN PILOT's Assistant calculates relative environmental impacts, comparing the impacts from each life cycle stage. No absolute numbers in terms of e.g. CO_2 or SO_2 equivalent can be expected but detailed guidelines how to improve a product. An instruction how to use this tool will be given in this chapter using the

water kettle. For those who are not able to perform an LCA (e.g. due to time and budget reason) the Assistant is recommended as an alternative for identifying ECODESIGN improvement strategies. Those who already performed an LCA as described in chapter 2 do not need to run the Assistant but can proceed with interpretation of the achieved LCA results as shown in section 3.6.

The questions to be answered within the Assistant along the product life cycle are given in six forms, one general form and five forms, one for each life cycle phase. These forms are described in the following.

Form 1 – General

When entering the ECODESIGN PILOT's Assistant the first form asks about some general data like: product name, product life time in years and the functional unit. The functional unit of a product describes the product's main function and indicates a quantity related to that function. For a washing machine this would be cleaning 5 kg laundry, for the water kettle we used: *Heating of 0.5 liter of potable water to boiling point* (see Figure 22).

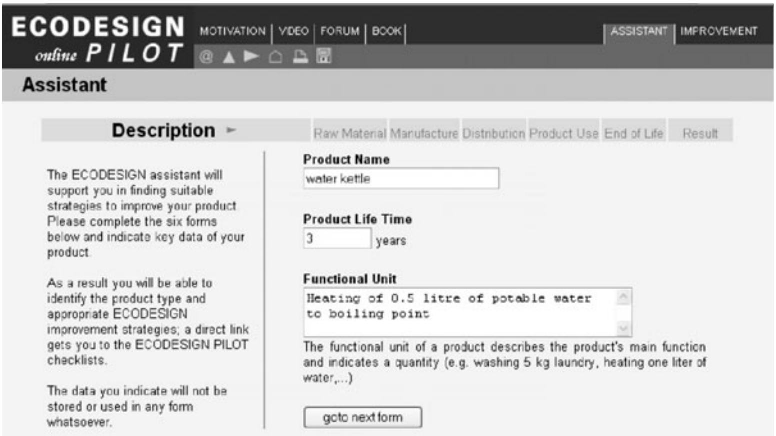


Figure 22 General form (ECODESIGN PILOT's Assistant).

Once one form is filled out there is a button at the end of each form to reach the next form addressing all stages in the product life cycle. The second form is consequently the one about specifying the use of raw materials stage.

Form 2 – Use of raw materials

Here the parts and components of a product to be analyzed have to be indicated by naming the product parts and giving the mass of the part in kg and by specifying the material of the part with so-called material classes. The same has to be done with packaging.

Since the focus is on the main parts and components, one has to answer the question if the product does contain parts that pose a hazard to the environment at the end of life without expert disposal. The idea is to find small quantities causing large impacts. Here soft answers like "yes", "unknown" or "no" are allowed. No detailed numbers need to be entered into the system. Figure 23 shows the second form of the ECODESIGN PILOT's Assistant.

The Assistant intentionally uses "soft" criteria and is able to calculate with these soft facts. Answers like "unknown", "rather yes", etc. are possible. Especially in the early phase in product development, this is a big advantage since the product definition is not finalized yet. The only way then is by working with rough (or vague) answers. The advantage of the ECODESIGN PILOT's Assistant is that although only vague answers are given or entered into the system, target oriented advice in the form of ECODESIGN strategies can be expected.

This advantage can be applied especially in the use of raw materials stage as shown in Figure 23. Here the designer might not have finished the specification of the materials of his product, but at the same time he might want to get advice on possible ECODESIGN strategies for his product. This is why within the Assistant material classes have been defined. Within these classes materials are grouped with more or less the same overall environmental impact concerning the use of raw materials stage (see Table 41).

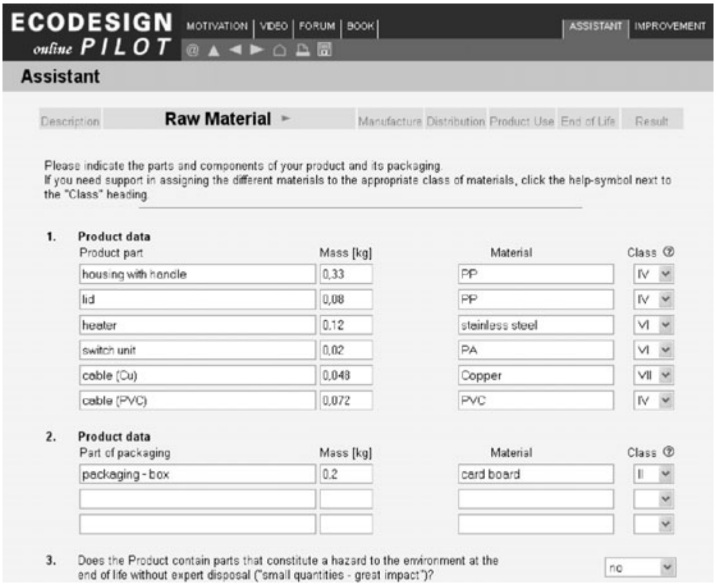


Figure 23 Form for use of raw materials (ECODESIGN PILOT's Assistant).

Once the designer has chosen a material class, he still has some freedom of changing materials without necessarily having to expect that the whole result of the analysis will change as well. With this feature the ECODESIGN PILOT's Assistant answers to feedback from industry, asking for that kind of flexibility in decision making.

Table 41 Material classes (ECODESIGN PILOT's Assistant).

	Metals	*Plastics*	*Other materials*
Class I			• Concrete • Wood, solid • Plaster
Class II	• Electric steel (secondary) • Aluminum (secondary) • Steel plate (90% recycled)		• Porcelain • Glass, bottles (recycled) • Sheet glass, (float glass) • Glass fiber • Linoleum • Cardboard • Paper (100% recycled) • Glass, container – (new)
Class III	• Steel (80% primary) • Steel (primary) • Steel, low-alloy		• Paper (65% recycled) • Leather • Rubber, green • Caoutchouc • Paper, free from chlorine • Rubber, raw • Coolant R134a • Ammonia NH3 • Fuel oil • Gasoline, unleaded
Class IV	• Cast iron • Sheet steel, galvanized • Cast steel	• PVC • HDPE • PP • LDPE • PPE/PS • PS • PET • SAN	• Rubber • Latex • Porcelain • Cellulose • Paper
Class V	• Copper (secondary) • Lead (50% primary) • Ferrochromium (53% Cr)	• PB • ABS • PE, foam • PUR, HR foam • PVDC • PU, non-rigid • PUR • PMMA (acrylic) • PC • PA 6.6 (nylon) • EP (epoxy resin) • PA (nylon)	• Glass fiber reinforced plastics (GRP) • Technical ceramic material
Class VI	• Steel, V2A: 18% Cr, 9% Ni • Steel, V4A: 17% Cr, 12% Ni		• Carbon fiber

(Continued)

Table 41 (Continued)

	Metals	*Plastics*	*Other materials*
	• Ferronickel (33% Ni) • Zinc alloys • Aluminum and Al-alloys • Steel, high-alloy (stainless) • Chromium • Molybdenum • Magnesium alloys • Copper (primary) and cables • Metal powder		
Class VII	• Titanium alloys • Copper alloys • Zinc • Copper alloys, bronze • Nickel and Ni-alloys • Silver		
Class VIII	• Palladium • Platin • Gold • Rhodium		

Form 3 – Manufacture

The third form refers to the key manufacture data of your product. Such as energy input (electrical energy in kWh as well as thermal energy in MJ), output waste per unit produced given in mass (kg) and material specified again with material classes. Experiences with companies have shown that these kind of data are either available within a company or can be measured or obtained easily.

For the energy input the overhead energy has to be specified also. The overhead energy is energy used for heating, lighting, cooling … in addition to the actual process energy. From energy balances in companies it is known that this overhead can go as far as 200%. To avoid misleading data here the overhead has to be specified as well.

Other information needed to grasp manufacturing is the form of disposal of production waste. The form allows the specification:

- through separation of materials
- with partial recycling of materials or as
- unsorted to waste

In order to understand the full dimension of the impact due to manufacturing the production volume has to be entered in units per year. This is later needed to calculate e.g. the total amount of waste. Again, only rough numbers are needed – production volume could be: less then 10, 10–10 000, 10 000–100 000 or over 100 000 pieces per year.

Additionally the input of environmentally hazardous auxiliary and process materials per unit produced, the percentage of external parts and the hauling distance for external parts per unit have to be entered in the third form.

Form 4 – Distribution

Next, data concerning distribution of the product are required. The average hauling distance (in km) and the means of transportation (ship, rail, truck, van, car or aircraft) used for the distribution of the product have to be indicated in this form.

Then the type of packaging – is it a disposable packaging or a returnable packaging needs to be specified.

Form 5 – Product use

For the product use stage the relevant data are frequency of use, given in uses per year, the material input per single use in mass (kg) and kind of material (material classes) as well as the electric energy input per single use in kWh.

Additionally, the danger of a potential hazard to the environment if the product is used inadequately or in the case of malfunctions has to be evaluated – simply with: probable, improbable or impossible.

Form 6 – End of life

The last form addresses the end of life stage. The parts and components entered in the second form are shown automatically and only the disposal scenario for each product part as well as for the packaging has to be specified. The possible options are:

- reuse
- recycling
- incineration
- landfill
- hazardous waste

Results of the ECODESIGN PILOT's Assistant

Once all six forms are filled out the ECODESIGN PILOT's Assistant has enough data to make a relative environmental evaluation between the different life cycle stages of the analyzed product. The result of this calculation is given then immediately.

Coming back to the water kettle we want to see and discuss the result of this application of the ECODESIGN PILOT's Assistant next (see Figure 24).

The result classifies the analyzed products according to so called "product types", which have been defined with respect to their main environmental impact along the product life cycle (Wimmer and Züst, 2002). These types are:

- Type A: Raw material intensive product
- Type B: Manufacturing intensive product

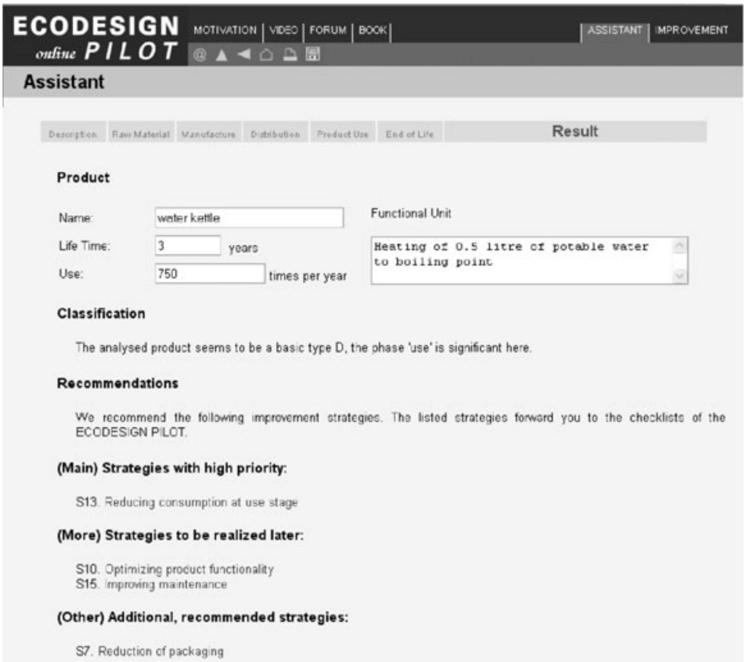


Figure 24 Result of ECODESIGN Assistant application for the water kettle (ECODESIGN PILOT's Assistant).

- Type C: Transportation intensive product
- Type D: Use intensive product
- Type E: Disposal intensive product

A product type indicated under "Classification" in the result page of the Assistant can be also a hybrid type like Type A, B. Then this product has a significant environmental impact in life cycle stages *use of raw materials* and *manufacture*.

Within "Recommendations" the Assistant points out ECODESIGN strategies to improve the analyzed product subdivided in:

- Main strategies with high priority
- More strategies to be realized later
- Other, additional recommended strategies

Those strategies listed as "main strategies" should be realized first, these have a high priority for the analyzed product and aims at the reduction of the most relevant environmental impact identified with Life Cycle Thinking. Then more strategies are mentioned that might be relevant as well, but with a lower priority. Environmental benefits obtainable through the realization of these strategies are lower but might be worthwhile to consider as well. Additionally, other strategies are recommended which address other environmental problems throughout the life cycle of the product (e.g. packaging), these issues can be

seen as minor details but worth to think about, since the realization can be performed in most cases with minimum effort. Best described with "picking the low hanging fruits".

For the water kettle the ECODESIGN PILOT's Assistant clearly indicates "Reducing consumption at product use stage" as the most important improvement strategy. This refers to the environmental impact caused by the energy consumption in the product use stage. Although the actual consumption for one time use is rather low (54.5 Wh, for boiling ½ liter of water) the total consumption accumulated (over 750 uses per year) over the entire products life (3 years) is significant here (122.6 kWh). Therefore, the reduction of the energy consumption throughout the entire life cycle is the main improvement option here.

The strategies "Optimizing product functionality" and "Improving maintenance" listed under more strategies to be realized later do not really apply to the water kettle, since we know for instance the maintenance necessary is descaling. This depends very much on the water hardness and cannot be improved with a modified design.

This is different from the additional recommended strategies. Here avoiding waste in the production process is referring to the injection molding process. Currently the runners are partly wasted and a full recycling could be carried out to improve it. If done within the production site, this would probably be also cost effective. Additionally to the procurement, ECODESIGN criteria should be considered. This refers to the externally purchased parts (e.g. heater).

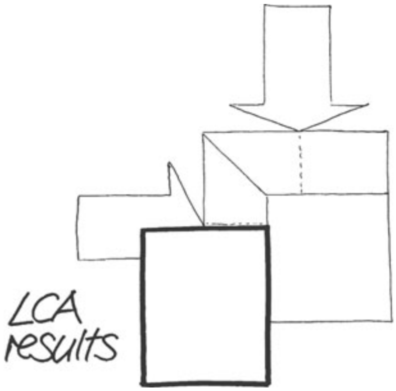
Finally, the Assistant detected also a weak point in the packaging. Obviously the packaging with 200 g cardboard seems to be quite heavy. A reduction can be achieved here as well, again probably with saving costs at the same time.

Summarizing what we found with the Assistant, we can mention "Reducing consumption during the product use stage" as the main improvement strategy.

Every improvement strategy listed in the result page of the Assistant is directly linked to the checklists of the ECODESIGN PILOT. Once following these links, one is guided through the detailed questions within the checklists to work out the appropriate ECODESIGN measures to redesign the product. This will be described in section 3.7.

The following section will examine confirmation of environmental aspects through interpretation of the LCA results.

3.6 Environmental aspects through interpretation of Life Cycle Assessment results



Another way to achieve an understanding about the significant environmental aspects of a product consists in performing an LCA as it was demonstrated in chapter 2, where the environmental impacts of the water kettle have been already analyzed in detail. The results of this LCA shall be interpreted here from the product development perspective. Interesting will be what can we learn from LCA results for redesigning the product.

Assume you got an LCA from your environmental department or from an external consultant. The main question now is: How to read an LCA, how to identify the key issues for product improvement? The key issues are one of the most important results of an LCA study and they become starting point for environmental improvement of a product by identifying weak points of the product to be redesigned.

Finding these weak points will be demonstrated in the following. It will be specified how to identify environmentally significant processes, materials and activities or even life cycle stages.

The significant issues of the water kettle were identified based on the environmental impacts calculated in section 2.3.3. Impact categories used were global warming (GW), acidification (AD), eutrophication (EU), photochemical oxidant creation (POC), and abiotic resource depletion (ARD). The Delphi-like panel method was applied to perform weighting.

Table 42 shows the characterized impact of the water kettle in all five relevant impact categories. Rows represent inventory parameters and columns life cycle stages. For each characterized impact category the main contribution, causing these impacts, as well as the percentage of the distribution along the products life cycle stages is indicated.

From Table 42 it is understood that most of the impacts in the categories global warming (93.30%) and acidification (91.86%) occur during product use, while most of the impacts in the categories of eutrophication (98.01%) and photochemical oxidant creation (80.88%) result from the use of raw materials stage. Meanwhile, the impact on the abiotic resource depletion is almost equally distributed between product use (55.86%) and use of raw materials stages (43.66%).

Table 42 Characterized impacts of the water kettle.

Inventory parameter	*Use of raw materials*	*Manufacture*	*Distribution*	*Product use*	*End of life*	*Total*
Global warming [g CO_2 equivalent/water kettle]						
CO_2	1500.53	995.53	241.43	35 561.25	−155.93	38 143.81
Methane		42.06		1 500.45	39.43	1 581.94
Total [%]	3.77	2.61	0.61	93.30	−0.29	100.00
Acidification [g SO_2 equivalent/water kettle]						
NO_x	3.82				0.08	3.90
SO_x	4.84	4.05		144.70	0.03	153.62
Total [%]	5.50	2.57		91.86	0.07	100.00
Eutrophication [g PO_4^{3-} equivalent/water kettle]						
NO_x	0.71				0.01	0.72
Total [%]	98.01				1.99	100.00
Photochemical oxidant creation [g ethene equivalent/water kettle]						
Methane		0.01		0.40		0.41
CO			0.04			0.04
VOC	1.76					1.76
NO_x	0.15				0.01	0.16
Total [%]	80.88	0.46	1.52	16.57	0.57	100.00
Abiotic resource depletion [g/water kettle-yr]						
Crude oil	15.01		1.82		−1.58	15.25
Coal	0.42	0.58		20.88	0.02	21.92
Chromium	0.12					0.12
Iron	0.75				−0.66	0.09
Total [%]	43.66	1.56	4.86	55.86	−5.94	100.00

In addition, the table also indicates which inventory parameters are significant in each impact category. For instance, CO_2, SO_x, NO_x, VOC and coal are the most significant parameters in global warming, acidification, eutrophication, photochemical oxidant creation, and abiotic resource depletion, respectively.

The question now is which is the environmentally most significant life cycle stage. Is it use of raw materials stage or is it product use stage? Therefore we have to look into the relative importance of the different impact categories. To derive a clearer picture highlighting the significance of the different impact categories weighting is needed.

Table 43 shows the weighted impact of the water kettle. We clearly see that the use of raw materials stage causes only a 12.54% of the total impact, whereas the product use stage causes 84.95% of the total impact.

In addition, Figure 25 shows the relative contribution of each life cycle stage and impact category to the total weighted impact of the water kettle.

The weighted impacts in both Table 43 and Figure 25 confirm that during the product use stage the most significant environmental impacts occur. With the weighted impacts, the relative significance among the different impact categories is now evident. Global warming is the most significant impact category – occurring in product use. In addition, it is also clear that the impact in the product use stage far

Table 43 Weighted impacts of the water kettle.

Impact category	*Use of raw materials*	*Manufacture*	*Distribution*	*Product use*	*End of life*	*Total*	*Share %*
GW	76.03	54.02	12.37	1898.92	−5.92	2035.42	65.7
AD	24.73	11.32		410.50	0.31	446.86	14.4
EU	11.17				0.16	11.33	0.4
POC	33.73		0.70	7.03	0.18	41.64	1.4
ARD	242.37	10.68	27.25	312.64	−33.24	559.70	18.1
Total [%]	12.54	2.45	1.30	84.95	−1.24	100.00	100.0

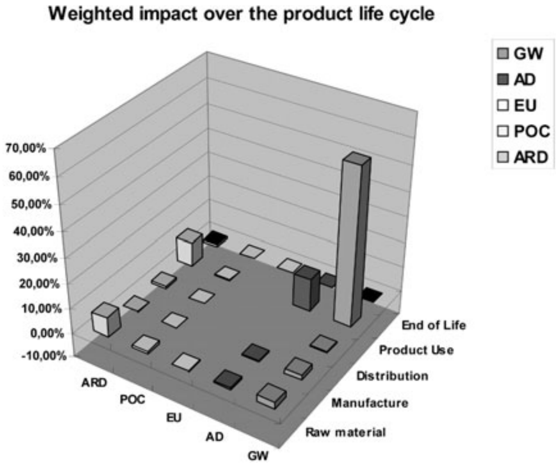


Figure 25 Relative contribution of the different impact categories along of the water kettle.

outweighs the impact in the use of raw materials stage. Impacts from the remaining three life cycle stages are negligible.

From the above analysis of the water kettle the following can be concluded:

Key activities: The most significant impact is the impact in global warming resulting from the CO_2 emissions of the water kettle from the electricity needed for heating water during the product use stage.

The abiotic resource depletion caused by the polypropylene manufacturing process, spanning from crude oil extraction to manufacturing of PP, is the second most significant activity occurring in the use of raw materials stage.

In addition, emission of SO_x from the product use stage is the third largest source of environmental impact. This is because of electricity generation emitted significant amount of SO_x due to coal combustion.

Key impact category: (% of the total weighted impact)	GW (65.7%) ARD (18.1%) AD (14.4%)
Key inventory parameter:	CO_2 (38,144 g) coal (6371 g) crude oil (615 g) SO_x (153 g)

The environmentally weak points or key issues identified from the LCA results are in full agreement with those from the ECODESIGN PILOT's Assistant. The only difference is that the former shows much more detailed points to improve, while the latter points out key issues in the life cycle stage. Accordingly, the consequences for the redesign process aiming at an improved water kettle have to focus on the energy consumption during product use. This is the key issue for any significant reduction of the environmental impact of the water kettle. Using ECODESIGN PILOT's classification the water kettle can be considered as a "use intensive product" (see Figure 26).

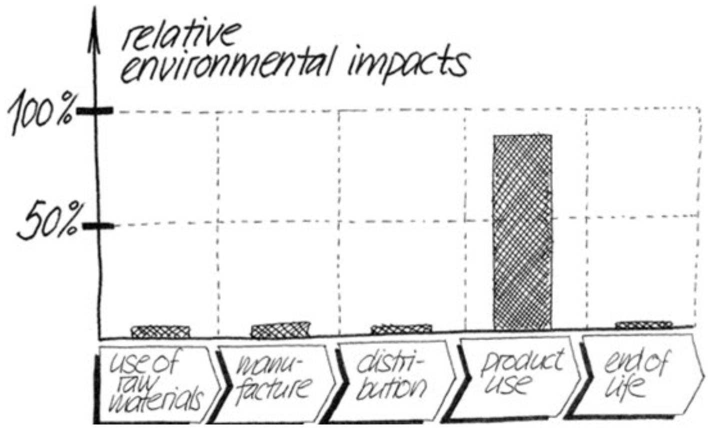
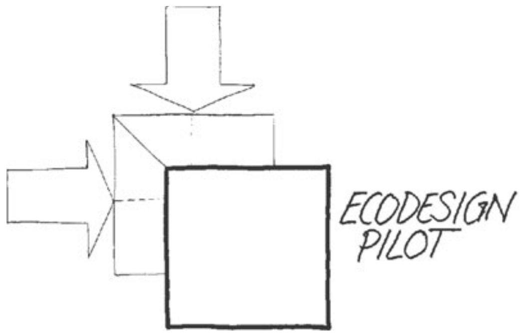


Figure 26 Characteristic of a use intensive product (Wimmer and Züst, 2002).

The next step consists of selecting appropriate ECODESIGN improvement strategies (see Figure 30) and guidelines to implement in an improved product (see section 3.7.2).

3.7 Applying the ECODESIGN PILOT



The ECODESIGN PILOT with its checklists is a kind of design evaluation tool that supports multidisciplinary working teams to find new ideas in product development. A workshop atmosphere for working with the PILOT should be strived for. A documentation of a creativity session using the ECODESIGN PILOT can be viewed on the ECODESIGN Video under www.ecodesign.at/video.

Do you know the ECODESIGN PILOT already?

If so, you probably used the CD-ROM from Wimmer and Züst (2002) or the web version of the ECODESIGN Online PILOT under www.ecodesign.at/pilot, which is in the meantime available in six languages (beside English they are German, French, Italian, Danish and Spanish, see Figure 27). The online version is freely available.

In this book the online version of the ECODESIGN PILOT is used, one will find there all product improvement strategies mentioned here.

Figure 27 Online version of the ECODESIGN PILOT.

The ECODESIGN PILOT consists of two main parts. One is dedicated to learning about ECODESIGN with knowledge pages; the other is for application of ECODESIGN using checklists (see Figure 28 and section 3.7.2).

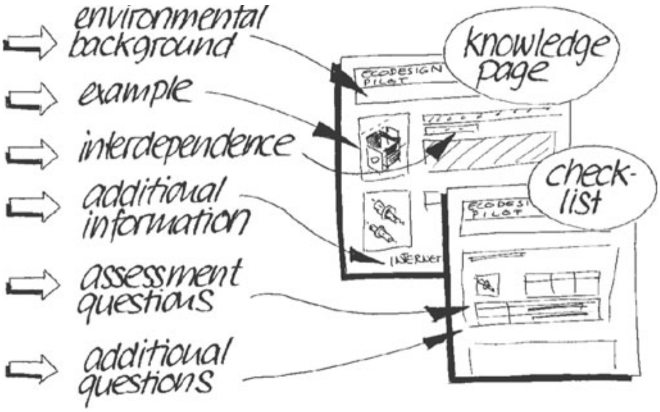


Figure 28 Main elements of the ECODESIGN PILOT.

The methodical approach for improving a product with the ECODESIGN PILOT consists of three steps. First, the basic type of a product is identified, second the improvement strategies are selected, and then checklists are worked through to determine ECODESIGN measures (see Figure 29).

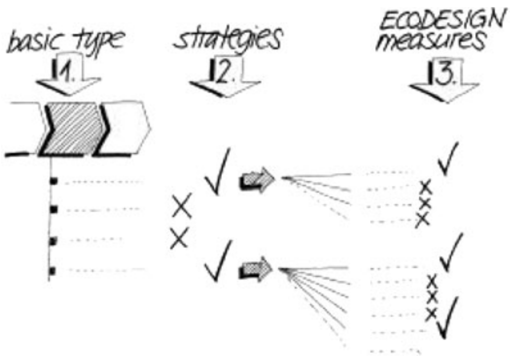


Figure 29 Methodical approach of ECODESIGN PILOT (Wimmer and Züst, 2002).

The question we want to answer now is: Which ECODESIGN strategies should be selected and which ECODESIGN measure should be followed when improving the product?

To do so the following steps are carried out and will be demonstrated:

- Deriving ECODESIGN PILOT's improvement strategies
- Identifying ECODESIGN measures with the ECODESIGN PILOT's checklists

3.7.1 Deriving ECODESIGN PILOT's improvement strategies

When it comes down to selecting appropriate ECODESIGN improvement strategies, we have to consider both perspectives again: strategies addressing the significant environmental aspects, but also strategies addressing stakeholder requirements. The question now is how to link both perspectives to common ECODESIGN strategies.

This first requires the water kettle to follow up with interpretation of the LCA results in finding strategies for a "use intensive product". Using the ECODESIGN PILOT the following strategies are recommended (see Figure 30).

Figure 30 Strategies for use intensive products (ECODESIGN PILOT).

Of the strategies listed "Reducing consumption at use stage" obviously is the only one matching with the LCA results (focusing on the energy consumption during product use). This is the same result as obtained from the application of the ECODESIGN PILOT's Assistant (see Figure 24).

Considering the stakeholder requirements the next step requires matching the environmental parameters, identified earlier with EQFD and EBM, to ECODESIGN PILOT's improvement strategies. This is done generically in Table 44. The use of this table can be demonstrated as follows: assuming the environmental parameter *weight* has been identified as important (either through EQFD or EBM), then the ECODESIGN PILOT's improvement strategy to choose would be *Reducing material inputs*. For every environmental parameter, one or two ECODESIGN improvement strategies have been assigned.

Table 44 Matching environmental parameters with ECODESIGN PILOT's improvement strategies.

Environmental parameters	*ECODESIGN PILOT's improvement strategies (Wimmer and Züst, 2002)*
General	
Weight	→ Reducing material inputs
Volume	→ Reduction of packaging
Supply parts env.	→ Ecological procurement of external components
performance	→ Reuse of product parts
Lifetime	→ Increasing product durability
Functionality	→ Optimizing product functionality
Use of raw materials	
Materials used	→ Selecting the right materials
Problematic materials	→ Selecting the right materials
Manufacture	
Production technology	→ Reducing energy consumption in production process
	→ Optimizing type and amount of process materials
Production waste	→ Avoiding waste in the production process
Distribution	
Packaging	→ Reduction of packaging
Transportation	→ Reduction of transportation
Product use	
Usability	→ Optimizing product use
Energy consumption	→ Reducing consumption at use stage
Waste (generated)	→ Avoidance of waste at use stage
Noise and vibrations	→ Optimizing product functionality
Emissions	→ Ensuring environmental safety performance
Maintenance	→ Improving maintenance
Reparability	→ Improving reparability
End of life	
Fasteners and joints	→ Improving disassembly
Time for disassembly	→ Improving disassembly
Rate of reusability	→ Reuse of product parts
Rate of recyclability	→ Recycling of materials

When applying Table 44 to the results achieved with EQFD (from Table 38) and EBM (from Table 40), the following ECODESIGN improvement strategies can be identified for the water kettle from the stakeholders' perspective (see Table 45).

Table 45 ECODESIGN PILOT's improvement strategies from stakeholder requirements.

Method	*Identified environmental parameters*	*Matching ECODESIGN improvement strategies*
Environmental Quality Function Deployment	Materials used	Selecting right materials
	Rate of recyclability	Recycling of materials
	Problematic materials	Selecting right materials
Environmental Benchmarking	Problematic materials	Selecting right materials
	Usability	Optimizing product use

When combining the resulting strategies from stakeholder requirements with those resulting from the significant environmental aspects, we can achieve a clear picture how to improve the water kettle. Table 46 specifies both perspectives and the recommended ECODESIGN strategies for the water kettle.

Table 46 Resulting ECODESIGN PILOT's improvement strategies for the water kettle.

Perspective	*Tools used*	*ECODESIGN improvement strategies*
Stakeholder requirements	EQFD and EBM (see Table 45)	Selecting right materials Recycling of materials Optimizing product use
Environmental aspects	ECODESIGN PILOT's Assistant (see Figure 24) or interpretation of LCA results (see Figure 30)	Reducing consumption at use stage

It is interesting to see from the difference in the resulting strategies that working only with one perspective is not enough. Assuming one would focus only on the environmental aspects definitely a significant reduction of the environmental impact can be achieved. However, at the same time the environmentally driven stakeholder requirements are not addressed at all. In order to meet the stakeholder requirements different redesign tasks have to be fulfilled. This is why it is important to always develop both perspectives at the same time. A systematic way to follow up is to use the checklists from the ECODESIGN PILOT.

3.7.2 Identifying ECODESIGN measures with the ECODESIGN PILOT's checklists

For each of the identified improvement strategies for the water kettle shown in Table 46 detailed ECODESIGN guidelines are available grouped together in checklists of the ECODESIGN PILOT. These checklists then can be applied to the product to be redesigned and ECODESIGN measures for improvement can be revealed when working through these checklists. This straightforward procedure will be demonstrated in the following.

Wimmer and Züst (2002) described the way to work with the checklists as follows:

"The ECODESIGN PILOT features a checklist for each of the selected strategies. By means of these checklists, you will subsequently be able to identify the appropriate ECODESIGN measures for product improvement.

Each checklist contains a strategy-related cluster of ECODESIGN guidelines. It will enable you to check if the product or parts of it fulfil the ECODESIGN requirements stated in the checklists.

The checklists have an assessment question for each ECODESIGN guideline. This assessment question aims at a potential improvement measure and has to be answered when you work through the checklists.

It will be shown that for a given product not all assessment questions are of equal importance. An ecology-oriented three-step prioritization will help to implement the selection:

1) Determining weighting (W):
   The relative importance of the individual assessment questions for a given product has to be determined. A rating of 10 points means "very important for my product", 5 points "less important for my product", and 0 points "not relevant for my product".
2) Performing assessment (A):
   The assessment question has to be answered using one of the four possible answers. Here, 1 point stand for "yes, has been fulfilled", 2 points for "rather yes, partly fulfilled", 3 points for "rather no, partly not fulfilled", and 4 point for "no, not fulfilled".
3) Determining priority (P) of ECODESIGN measure:
   The value of priority P is calculated by multiplying weighting W by the value of assessment A. Therefore, possible values for P are 40, 30, 20, 15, 10, and 0.

Working with the checklists starts with identifying the most promising ECODESIGN guidelines. They are characterized by a high P value (priority). Activities should focus on these guidelines because they have a high improvement potential for the product in question."

For each of the four identified strategies in Table 46 the above described procedure has to be applied. This chapter shows the summary of this application. Each checklist item shall be discussed within the design team. Figures 31 to 38 show relevant checklist items with high priority out of a run through of the four selected strategies. For each of these checklist items considerations and remarks are noted to better understand the design team's assessment.

When looking at the Life Cycle Thinking or LCA results the design team was motivated to start working on ECODESIGN ideas to reduce the energy consumption during use.

Strategy: Reducing consumption at use stage

The question in Figure 31 is that whether the product can be used in a way which was not intended – especially connected to energy consumption. A possible misuse is addressed.

In the picture washing machines are shown – one half full the other full – to clarify that the checklist tries to stimulate associations. When operating a half full washing machine (unless the machine is equipped with sensor able to detect amount of laundry filled in) the same amount of water is used compared to a full washing machine. This could result in higher energy consumption per functional unit (e.g. washing 5 kg laundry).

Basically the same consideration can be applied for the water kettle. When filling up the water kettle to boil a full kettle of water and using then only one or two cups of hot water for preparing a tea, the energy for heating the remaining water is wasted. From the benchmarking we know the maximum water content of the kettle is 1 liter. The energy consumption for boiling 1 liter of water was measured 109 Wh. Here we are aiming at preparing 3 cups of tea for tea break in office. This equals half a liter of

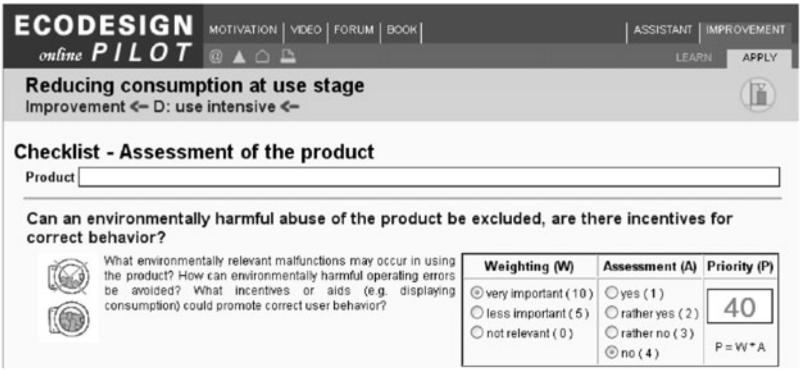


Figure 31 Checklist item (ECODESIGN PILOT).

water and a measured energy consumption of 54.5 Wh. When completely filling up the water kettle and using only hot water for 3 cups half of the energy required is wasted. Environmental abuse could be prevented through guidance to use the right amount of water by some kind of instruction on the water kettle, so the user is not wasting heated water and therefore energy.

Since we are designing socio-technical systems we have always to consider the users behavior. If we are looking at the use of a water kettle within an office it might happen, that someone wants to prepare tea, therefore starts the water kettle but forgets actually about that. When finally remembering to drink tea the water might be still warm, but the user does not get any feed back from the kettle and might re-boil the water. This could be again an environmental abuse happening most likely. What does this mean in terms of energy consumption? Measuring a test scenario yielded the following results:

Boiling of ½ liter of water required 54.5 Wh.

After 10 min of waiting a re-boiling required another 15.5 Wh.

The re-boiled water for ½ liter of tea consumed in total 70 Wh.

The ECODESIGN measure mentioned in the checklist is:

Prevent environmentally abuse of product.

The next assessment question in Figure 32 addresses the indication of the level of consumption. This might look as "not relevant" but by going into the details a kind of "indication" might be useful e.g. in the light of the previous mentioned problem of preventing re-boiling. A kind of signal indicating readiness (e.g. a lamp indicates that the water is still warm) could help to avoid the re-boiling behavior.

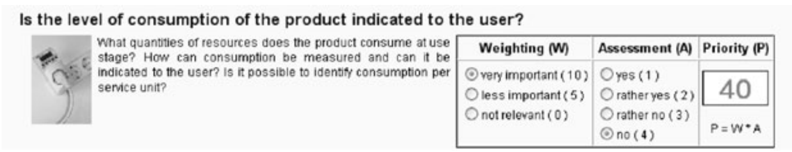
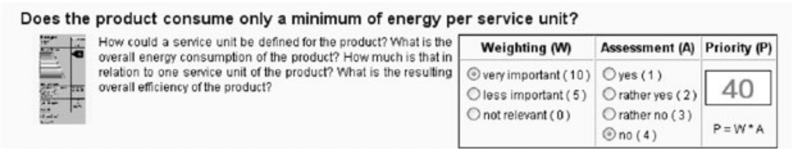


Figure 32 Checklist item (ECODESIGN PILOT).

The ECODESIGN measure mentioned in the checklist is:

Indicate consumption of product along use stage.

The question if the product consumes only a minimum of energy per service unit, as given in the next checklist item in Figure 33 raises the question what the actual "minimum" might be.


Does the product consume only a minimum of energy per service unit?

How could a service unit be defined for the product? What is the overall energy consumption of the product? How much is that in relation to one service unit of the product? What is the resulting overall efficiency of the product?

Weighting (W)	Assessment (A)	Priority (P)
◉ very important (10)	○ yes (1)	40
○ less important (5)	○ rather yes (2)	
○ not relevant (0)	○ rather no (3)	P = W * A
	◉ no (4)	

Figure 33 Checklist item (ECODESIGN PILOT).

Assuming boiling half a liter of water (this equals three cups) starting from a temperature of 20° Celsius, we can calculate the minimum energy needed as follows:

$E_{therm} = m \times c_w \times \Delta T$

E_{therm} is the minimum energy required

m is the mass of the water boiled (0.5 kg)

c_w is the specific heat content of water (4.186 KJ/kgK)

ΔT is the temperature difference (80 K)

According to that calculation the minimum energy consumption is 46.5 Wh.

Comparing this result with the measured energy consumption of 54.5 Wh and 70 Wh (with re-boiling) we can see the water kettle is not consuming only a minimum of energy per service unit – actually, the kettle is consuming a lot more.

When measuring the actual energy consumption needed for boiling half a liter of water (this was 54.5 Wh) we observed that the water was already boiling at an energy consumption of 48 Wh. Since we also measured the temperature along the heating process, we could clearly see that boiling temperature was achieved already at that time and boiling continued until the device finally switched off automatically. The automatic switch has a long lag time, which leads to wasting energy again.

The ECODESIGN measure mentioned in the checklist is:

Minimize energy consumption at use stage by increasing efficiency of product.

When answering the question about the energy-efficient principle of functions as displayed in Figure 34 we have to compare the energy consumption of 48 Wh (water is boiling) and the required minimum energy consumption of 46.5 Wh. We can see that the chosen principle of transforming the electrical energy into thermal energy is quite efficient. This could have been expected since the heater coil is located directly in the water. No heat loss due to thermal radiation occurs.

The reason why this checklist question is still getting a high priority is because of the heat losses due to bad insulation of the water kettle. We measured a temperature difference of 20°C within only 10 minutes.

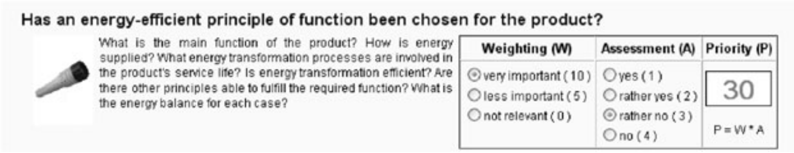


Figure 34 Checklist item (ECODESIGN PILOT)

The ECODESIGN measure mentioned in the checklist is:

Minimize energy demand at use stage by choosing an adequate principle of function.

The remaining checklist items out of the strategy "Reducing consumption at use stage" do end up with a low priority or are not relevant at all. Nevertheless, the other strategies mentioned in Table 46 are also delivering ECODESIGN measures to implement within the redesign and are listed below.

Strategy: Optimizing product use

Benchmarking brought up the different product performance during the product use stage. The question in Figure 35 is about easy handling of the product. This can be improved and one competitor is already doing this by using an extra ground plate for free movement of the water kettle.

The ECODESIGN measure mentioned in the checklist is:

Design product for easy handling.

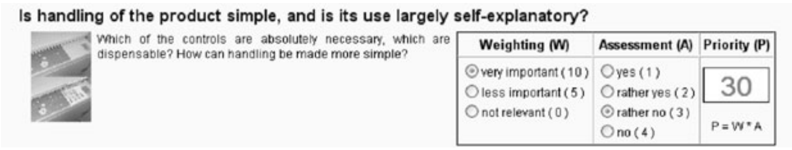


Figure 35 Checklist item (ECODESIGN PILOT).

Strategy: Selecting the right materials

Environmentally aware users examine carefully toxic or problematic materials that the product might contain (Figure 36). This is expressed with requirements of RoHS directive (e.g. lead), but also with the requirements from eco-labels. The Nordic Swan scheme for instance does not allow PVC in a water kettle as explained in section 3.2.5.

The ECODESIGN measure mentioned in the checklist is:

Avoid or reduce the use of toxic materials or components.

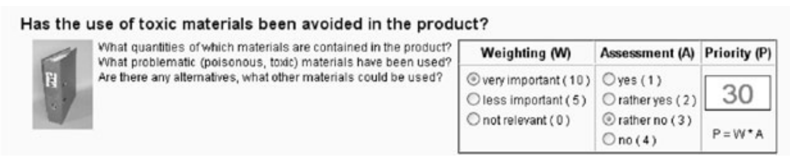


Figure 36 Checklist item (ECODESIGN PILOT).

Strategy: Recycling of materials

The WEEE directive requirements can be addressed with the strategy “Recycling of material”. This checklist (Figures 37 and 38) brings up two more ECODESIGN measures.

Ensuring or exceeding a recycling rate of 50% is targeted with WEEE for small household appliances.

The ECODESIGN measure mentioned in the checklist is:

Make possible separation of materials for recycling.

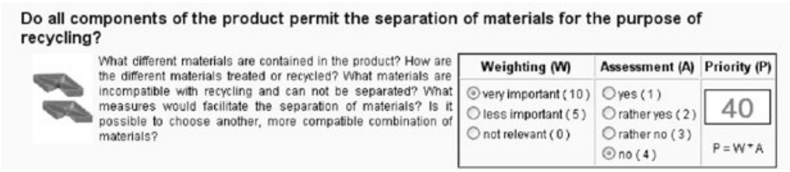


Figure 37 Checklist item (ECODESIGN PILOT).

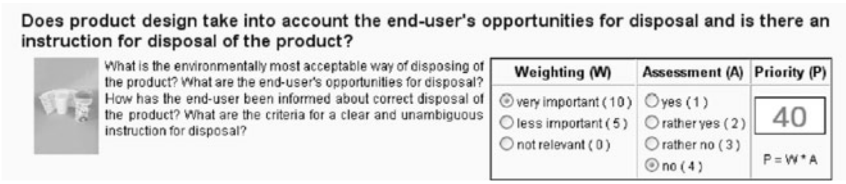


Figure 38 Checklist item (ECODESIGN PILOT).

The end users opportunities and behavior has to be considered for the disposal of a product according to WEEE. A logo has to be printed on each product advising not to dispose of but bring it back for recycling (see Figure 39).

Figure 39 WEEE symbol for marking products.

The ECODESIGN measure mentioned in the checklist is:

Take into account end-user’s opportunity for disposal and provide for instructions for disposal.

The idea of this section was to demonstrate how to work with the checklists of the ECODESIGN PILOT aiming at finding ECODESIGN measures to implement.

3.7.3 Summarizing the ECODESIGN tasks

In the next step the ECODESIGN measures described generically have to be translated into specific redesign tasks for the water kettle. This is listed in the Table 47.

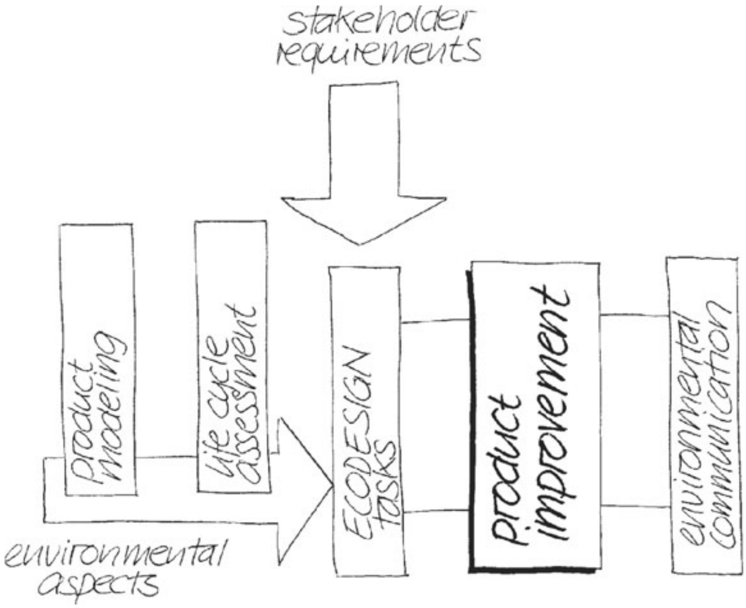
The ECODESIGN tasks for improving the water kettle are clearly identified now and the actual product improvement process can start. Details about product development are described in chapter 4.

Table 47 ECODESIGN measures and ECODESIGN tasks for the water kettle.

ECODESIGN measures to implement	*ECODESIGN tasks for improving the water kettle*
Prevent environmentally abuse of product.	Give guidance for filling in the "right" amount of water. Provide information when the water is ready to avoid re-boiling.
Indicate consumption of product along use stage.	Measure water temperature and indicate readiness to avoid re-boiling.
Minimize energy consumption at use stage by increasing efficiency of product.	Provide sensitive automatic switch off with shorter lag time.
Minimize energy demand at use stage by choosing an adequate principle of function.	Insulate the housing to avoid heat loss (and prevent re-boiling).
Design product for easy handling.	Separate cable from housing for easy handling, allowing free movement.
Avoid or reduce the use of toxic materials or components.	Phase out PVC and lead.
Make possible separation of materials for recycling.	Improve fasteners for easy separation of materials.
Take into account end-user's opportunity for disposal and provide for instructions for disposal.	Mark the water kettle according to WEEE.

Chapter 4

PRODUCT IMPROVEMENT



The ultimate goal of ECODESIGN is to develop improved products. The ECODESIGN tasks are clarified and this chapter proceeds seeking for actual product improvements. Thereby the product development process is addressed in five steps, which are: product specifications, functional structure, creativity sessions, product concept as well as embodiment design.

The chapter demonstrates a target-oriented approach throughout the entire phases of the product development process aiming at an optimal solution fulfilling the listed product specifications.

At the end of this chapter a new concept for an improved water kettle can be expected.

4.1 Introduction

A close look into customers, legal and other requirements, into competitor's product performance and into the environmental performance of the product during its entire life cycle clarified the ECODESIGN tasks for redesigning the product, but how to proceed now to achieve an improved product?

Generally, the product development process is combining different disciplines, interests and expertises into marketable products. The actual way to accomplish product development differs from company to company but has common general steps and tries to give answers to general questions such as (Pahl and Beitz, 1996):

- How to formulate product specifications for the redesign process?
- What are the relevant product functions to be considered?
- How to stimulate new ideas in product redesign?
- How to combine ideas to a product concept?
- How to continue with embodiment design for a better product?

The general steps in product development to answer these questions are shown in Figure 40. These steps will be used as structure of this chapter and will be addressed briefly using the water kettle example.

Product improvement consists of five elements:

- The first step of every product development process is to list the product specifications that shall be achieved. This step is essential and initiates every product (re)design process. This is demonstrated in section 4.2.
- The redesign process as suggested here follows up with developing the functional structure of the water kettle. Working with functions is introduced in section 4.3. The idea is to highlight relevant functions appropriate for design improvements.
- This is followed by creativity sessions and patent search for finding principal solutions for each relevant function (see section 4.4).
- Possible solutions for the functions are selected and put together in a common scheme – the morphological box, where the concept design work can be

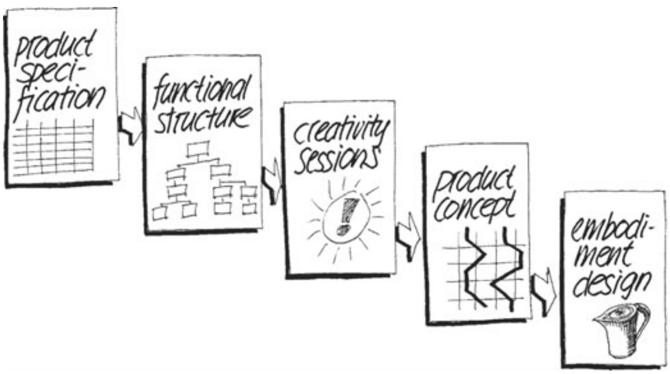


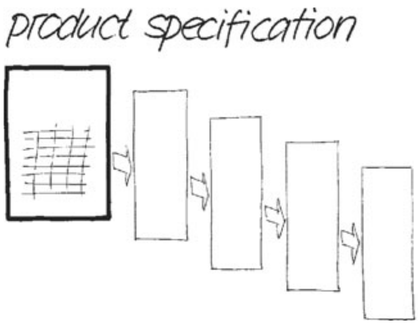
Figure 40 Steps for product improvement.

started with assembling ideas and generating product concept variants, followed by an evaluation and selection of the best variant (see section 4.5).

- A summary of the redesign tasks and hints for the final embodiment design is given at the end of section 4.6.

After formulating ECODESIGN tasks for product improvement in section 3.7.3, an engineer or designer actually does not need further help to implement the ECODESIGN tasks in an improved product. For an experienced product developer from there on the way to go should be clear. Nevertheless, for those without an engineering design background the remaining way to an improvement product should be pointed out. Since there are many ways to find a final solution, only a methodical guidance in the form of a step-by-step approach will be given. The actual technical application will be left up to the reader. Improved water kettles from different design teams will probably look different, but will have common design elements. Essential is to find the right starting point and to give methodical guidance about how to proceed, which is considered most important.

4.2 Product specifications



The list of product specifications is the important starting point for all following working steps in product development. The product specifications shall comprise all quantitative and qualitative data and shall serve as a basic document for any product development process.

Environmental considerations from different perspectives have to be formulated in a list of product specifications to start the product re-design process.

Table 48 lists the product specifications for the water kettle deduced from the ECODESIGN tasks in section 3.7.3. It is important to formulate the specifications in a neutral way, allowing new ideas to arise in later phases of the product development. Pre-describing of possible solutions shall be avoided. To give an example "install lamp" would be neglecting that other forms of signals do exist (e.g. ringing a bell), "install signal" would be the neutral formulation of the specifications, not narrowing down the spectrum of possible solutions.

Each specification in Table 48 is assigned to a relevant life cycle stage and an explanation of the specification is given. Furthermore, the type of specification is classified. There are basically two types: fixed and optional specifications. The fixed

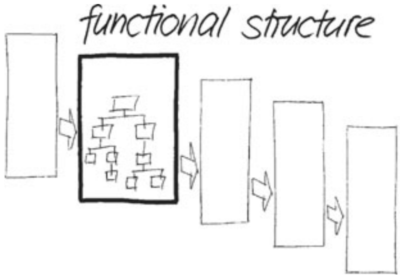
specifications have to be realized in the product in any case. The optional specifications are adding value, but need not necessarily to be fulfilled from the product concepts developed later.

It should be mentioned that the focus is on environmental specifications only; other specifications (e.g. costs, quality) can be treated in the same way, but are out of the scope of this book.

Table 48 Product specifications for an improved water kettle.

Life cycle stage	*Type of specification*	*Name of specification*	*Explanation and value*
Environmental product specifications:			
Use of raw materials	fixed	Phase out lead and PVC	Substitute lead and PVC according to the RoHS and Nordic Swan requirements
Product use	optional	Guidance for filling in water	Cup indication for 1 to 6 cups
	optional	User information	Give information to alert when water is ready
	optional	Water temperature	Measure and indicate water temperature in a range from 50° to 100°C
	fixed	Automatic switch off	Reduce lag time of switch to <2 s
	optional	Insulate housing	Keep temperature for minimum 20 min
	fixed	Separate cable	Allow free movement with kettle, without unplugging
End of life	fixed	Fasteners	Improve easy separation of materials for high recycling rate (WEEE)
	fixed	Marking the kettle	Give the end of life information according to WEEE
Other product specifications:			
Those are not listed here …			

4.3 Functional structure



A core element in developing products is thinking in functions the product should deliver in order to fulfill a need. For instance, the function of an electro motor would be “generating torque”, that of a gearbox would be “converting torque”. The function of a screw could be “connecting parts”. From that we can see that a welding spot or an adhesive-bonded joint would have the same technical function as a screw. This is why we can use technical functions on our way from an abstract idea to a concrete (detailed) product design.

To avoid misunderstandings, the “functional unit” as employed earlier in the previous chapters is a different expression. While the functional unit expresses a reference value of the overall performance of the product, the functions meant here refer to technical functionality the product shall provide.

We can express with functions what the product should be, without specifying for the time being, what it should look like in detail. Engineers in product development take advantage of this approach to develop a product concept in a step-by-step manner. This approach is often called function synthesis.

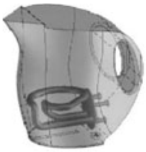
Synthesizing functions is an engineering technique that aims at developing product concepts out of an overall function of a product. For a washing machine the overall function would be “cleaning clothes”. The overall function is then broken down into main and sub functions, which contribute to the overall function. For each identified function possible “physical effects” are searched and appropriate “working principles” as well as “principle solutions” are found. To give an example Table 49 demonstrates for the technical function “measuring temperature” what this function synthesis could look like.

Table 49 Function synthesis.

Technical function	*Physical effects*	*Working principles*	*Principle solutions*
Measuring temperature	Thermal expansion	Bimetal spring	
	and others …	and others …	and others …

The result of such a process is normally a broad variety of principle solutions, especially when considering different physical effects but also when varying the

Table 50 Function analysis of water kettle.



Main parts	*Main functions*
Housing	Hold water
Heater	Heat water
Switch unit	Switch off automatically
	Avoid overheating
Cable	Supply with electricity

properties of working principles. Consequently, various different principle solutions can be achieved. For the process of systematically developing principle solutions different techniques do exist to narrow down the number of possible combinations.

Another way of working with functions is using functions for a systematic analysis – called function analysis.

The idea with function analysis is to identify for every product part the function(s) this part is fulfilling (e.g. the motor of a washing machine is providing the function turning the washing drum). Then this function can be described generally, not mentioning a certain solution (e.g. providing movement of laundry).

This function analysis for the water kettle addressing main parts and assigning main functions is presented in Table 50.

The functions derived from a function analysis can also be used to perform a value analysis to point out costs per function. This is sometimes an eye opening process, since engineers are mostly used to think in costs per part rather then in costs per function, which is the result of a value analysis. Therefore, working with functions can also be used to gain insight into potentials for cost reductions by identifying cost intensive functions. This can be done according to Table 51. Within the matrix between parts and functions, the fulfillment of the function is expressed by a percentage. The prices of the parts in Table 51 are fictional numbers.

Table 51 demonstrates that the most expensive function is *hold water* followed by the function *switch off automatically*. In order to improve costs these two functions should be addressed first in this example.

Table 51 Value analysis for the water kettle.

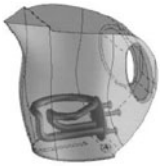
Functions	*Parts*				
	Housing [8 €]	*Heater [4 €]*	*Switch unit [4 €]*	*Cable [2 €]*	*Cost per function*
Hold water	80%				6.4 €
Heat water		80%			3.2 €
Supply with electricity				100%	2.0 €
Avoid overheating		20%	50%		2.8 €
Switch off automatically	20%		50%		3.6 €

To complete the functional structure the ECODESIGN tasks from section 3.7.3 need to be analyzed. Some of them require additional functions of the water kettle, some require improving of existing functions, others require both. There are also ECODESIGN tasks, which do not need any translation into functions, but can be put

into action directly. They are: *phase out PVC and lead*, *improve fasteners for easy separation of materials* and *mark the water kettle according to WEEE*.

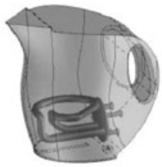
Table 52 lists the additional functions needed in an improved water kettle.

Table 52 Additional functions needed.

	ECODESIGN tasks	*Additional functions needed*
	Give guidance for filling in the "right" amount of water.	Show water level
	Provide information when the water is ready, to avoid re-boiling.	Show water temperature
	Measure water temperature and indicate readiness, to avoid re-boiling.	Measure water temperature
	Insulate the housing to avoid heat loss (and prevent re-boiling).	Provide insulation
	Separate cable from housing for easy handling, allowing free movement.	Allow free movement

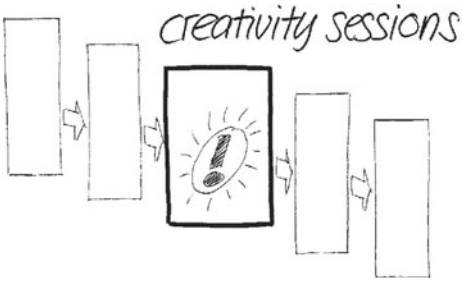
Apart from the new functions to add there are existing functions to improve – see Table 53.

Table 53 Existing functions to be improved.

	ECODESIGN tasks	*Existing functions to improve*
	Provide sensitive automatic switch off with shorter lag time.	Switch off automatically
	Separate cable from housing for easy handling, allowing free movement.	Supply with electricity

After developing an understanding about functions, new ideas are needed to find solutions for these functions – hints for that are described in 4.4.

4.4 Creativity sessions



Product development in general is a combination of creative and methodical elements. Both elements are necessary to make sure to develop an optimal product. An engineer experienced in product development knows when to perform creativity sessions and when to follow a methodical step-by-step approach. Creativity sessions could be done after the definition of the ECODESIGN task (or product specifications) or latest once the functions of the product are defined and solutions for the functions are aimed at.

4.4.1 Creativity techniques

Creativity is needed for coming up with new ideas or solutions for known (or new) problems. In general, the creativity process follows four steps known as: preparation, incubation, illumination and verification of ideas. Normally it is easier to deal with known problems as with new ones, since solutions to those are already known and it is easier to create new ideas. Therefore, most creativity techniques use alienation for that purpose. Once a problem is understood, one tries to find a similar problem within another area or field (e.g. in nature), searches for solutions there and translates back to the solutions found (e.g. bionic). Along these lines new ideas might be derived for solving an original problem. Techniques using this effect of analogies include:

- Synectic – personal or other analogies are used
- Bionic – analogies in nature are searched
- Theory of Inventive Problem Solving (TRIZ) – technical analogies are used to provide solutions to a pre-defined problem

If an original problem is approached with an analogy, normally the original problem is transferred to an abstract level. There a solution is searched for and most of the time found easier (e.g. predefined standard solutions in the form of innovative principles in TRIZ). The last step consists of translating the solution found back into the original problem area, assuming a solution for the original problem can be derived. It works quite well and eases the way to new ideas in product development.

Besides looking for analogies, there are other ways of stimulating new ideas; these include intuition, variation or researching. Intuition can be used in different ways that one is provoking new ideas. This is for instance applied in anticipated failure detection. Instead of solving an original problem, one is searching for solutions for an inverted problem and inverts the results later. Imagine you are looking for measures to

increase safety of your system or product. This is sometimes difficult since you should consider all possible safety risks. If you instead brainstorm about ideas “How to provoke an accident?” you probably get more ideas than the other way around. Later you simply invert the found measures again and use these ideas to avoid accidents.

In general, when doing creativity sessions an open atmosphere is needed and “out of the box” thinking should be supported – a kind of workshop culture is needed for many of these techniques. Discussions are normally an essential element of such creativity session, but might hamper the flow of new ideas at the same time (e.g. due to dominant opinions). The problem occurs especially within a hierarchy of a company. This is why brain writing, the “silent” way of brainstorming, is recommended here. Whenever the creativity potential of a group should be used to derive a significant number of new ideas within short time brain writing is recommended.

Table 54 shows a possible result of a brain writing session after the first five minutes. In total, the session lasts only half an hour and delivers normally a significant number of new ideas. Six participants, seated in circle, write down three ideas within five minutes, then they hand over their forms to their right neighbor and try to develop further the ideas they got from their left neighbor with another three proposed own ideas. This goes on until all six forms are completed. It is strongly recommended to use drafts and small drawings rather than long text to explain own ideas.

Table 54 Brain writing form after the first five minutes.

Brain writing task: Finding ideas for “Showing water temperature”			
Person	*1st idea*	*2nd idea*	*3rd idea*
1	red – green lamp 	analogue 	digital **85°C**
2	…	…	…
.			
.			
6	…	…	…

After the brain writing session a moderator is summarizing the six completed forms, groups the ideas and presents the findings to the participants in a next session. Then an evaluation of the achieved ideas and further processing of these ideas is decided.

4.4.2 Patent search

A very valuable source for new ideas is of course a patent database. Patents are by their nature documented new ideas. In the Europe’s Network of patent database, which is accessible in English (see Figure 41), one can find access to worldwide patents documented with title, abstract, description and drawings.

From the patents description one should be able to understand the whole product idea or invention. Not every patent is still valid, there are a lot expired patents serving as idea pool for creating new ideas. Although it might be difficult for a beginner to do a patent search, this instrument is a valuable source for new ideas.

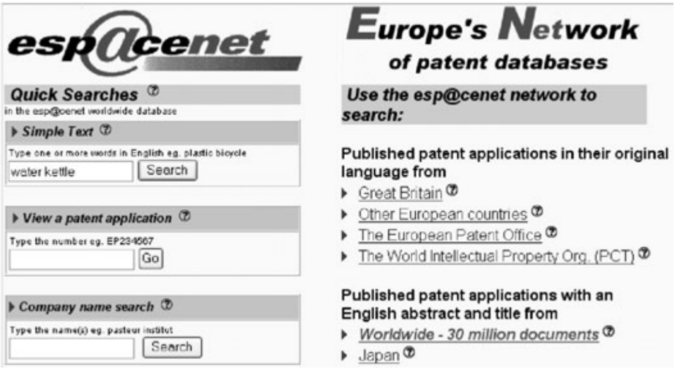


Figure 41 Interface of the Europe's Network patent database (gb.escpacenet.com).

Within a patents search for water kettle similar designs can be found e.g. patent GB2223160 – shown in Figure 42. With that patent an idea is mentioned that provides within a regular water kettle a small chamber, for heating efficiently only a small amount of water (e.g. one cup).

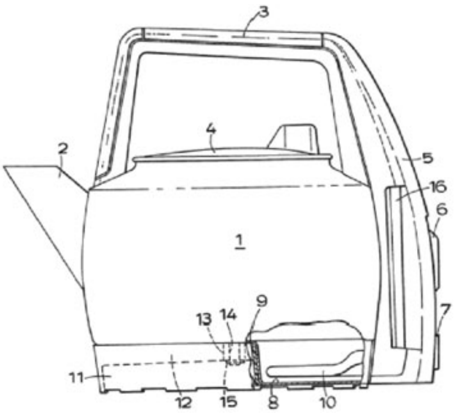


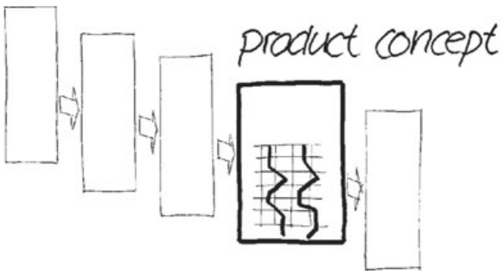
Figure 42 Patent GB2223160.

What we can learn from the patent search is to understand what our competitors are doing and what the latest developments are in a certain product area. This allows us to find or even stimulate the development of new ideas but also to avoid conflicts with existing patent rights.

It might also be very useful to perform a patent search within another area rather than this where the original problem or product is located. There might be some solutions already developed for other purposes but valid also for the original problem – again analogies can be used. Moreover, from expired patents we can derive elements and use them in our designs.

The stimulation of new ideas is essential in product development. Each engineer has to find his own way to make best use out of the wide variety of methods and techniques for creativity.

4.5 Product concept



Support for combining new idea into a new product concept is described here. The functions to be added to the product are identified; techniques to find new ideas have been demonstrated. The next question is how we can combine both – thinking in functions with generation of new ideas. This is best done with the so-called morphological box. What this is and how it works will be explained in this section.

The morphological box is a main element in developing product concepts from abstract to detail within a target-orientated search for an "optimal" solution. A good engineer always develops different variants before evaluating and selecting one version to develop further into a prototype and finally into a product for the market.

This is where the morphological box is used.

Once the functions of the product are identified, including those, which should be added, possible solutions for the functions are searched for. Working with functions in that way allows breaking down the far more complex task of re-designing the whole product into less complex tasks of finding new solutions for fulfilling individual functions. This is easy to grasp and manageable.

For each function several ideas shall be developed by using creativity techniques such as mentioned earlier in section 4.4. Of course solutions for functions can be worked out very systematically also with function synthesis as described in section 4.3. In any case, taking apart the problem solving task into smaller portions to solve these and assemble the achieved solutions again at the end is a well known practice not only in engineering design.

The morphological box (as shown in Table 55) is the documented form of finding ideas for function fulfillment. In principle, every individual solution of an individual function can be combined with any other solution of another function. The result can be a large number of possible product concept variants.

In Table 55 the new functions to be added to the water kettle are most interesting. Therefore it shall be first discussed with the two functions "measure water temperature" and "show water temperature". These two functions are needed together in order to give the user a feedback if re-boiling is required or not. Measuring the

Table 55 Morphological box for the functions of the water kettle (partially filled out).

Functions	*Possible solutions for functions*		
Hold water	Big jar (1 l)	Small jar (½ l)	…
Heat water	Heater coil inside jar	Heater outside stainless steel jar	…
Switch off automatically	Bimetal switch	Thermal sensor (resistant)	…
Avoid overheating	Bimetal switch	Thermal sensor (resistant)	…
Supply with electricity	Cable	…	…
Measure water temperature	Against fixed threshold value	Against adjustable threshold value	…
Show water temperature	Red – green lamp 	Analogue 	Digital 85°C
Show water level	Mark in liter from aside	Mark in cups from aside	Mark in cups from above
Provide insulation	Double wall with air insulation	Insulating foam	…
Allow free movement	Ground plate	…	

V1 **V2**

temperature can now be done against a pre-defined (fixed) threshold value and could be displayed accordingly (temperature is below or above).

Assuming tea is prepared with hot water of which the right temperature varies from 50°C, which is the maximum temperature for high quality green tea (e.g. Sencha, Gyokuro, SeJac) up to 80°C for black teas (e.g. Assam). For coffee the ideal brewing temperature is 95°C. Consequently both functions could be realized with an adjustable threshold with a range from 50°C to 95°C. This of course has to be in line with the marketing and general product strategy. This additional functionality would in any case fulfill the requirements from environment (avoiding re-boiling), from customer (easy to use) and from benchmarking (competitive advantage).

Another new function, easy to realize, would be "show water level". This could be done with liter indication or better with cup-marking at the housing. The user usually thinks in cups rather than in liter (How many cups is one liter?). "Provide insulation" goes together with the effort of avoiding re-boiling and makes sense only together with the functionality described above. "Allow free movement" – this function is required to scope with the competitor's features. The user already expects that.

4.5.1 Combining variants

Every cell of the morphological box represents a possible solution for an intended function of the product. To achieve a product concept variant for each function one solution (therefore one cell) has to be selected and combined with solutions from other functions (see lines in Table 55).

Accordingly, in principle a huge variety of variants can be combined. To reduce the complexity several techniques are available such as:

- Focusing on the design dominant elements (e.g. main functions)
- Cluster in solution classes (e.g. fully mechanical solutions)

For the water kettle improvement the three functions "measure water temperature", "show water temperature" and "show water level" are considered dominant for the re-design. The chosen variants are therefore based on those functions – variant V1 and V2 have been selected as examples out of more possible combinations.

4.5.2 Evaluating concept variants against assessment criteria

The final step in developing a product concept consists in evaluating the product concept variants and selecting a specific variant. For continuing the water kettle example the evaluation shall be based on environmental specifications from Table 48. Working with weighting of specifications and assessing the degree of fulfillment of specifications is a possible way to select concept variants. This is shown in Table 56.

Table 56 Evaluation of concept variants based on environmental specifications.

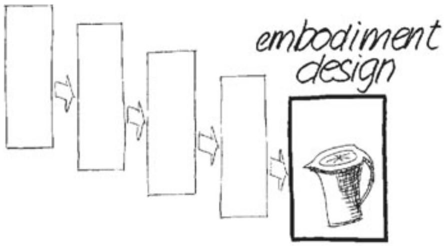
Type of spec.	*Name of specification*	*Value and explanation*	*Weight*	*Fulfillment*	
				V1	*V2*
Optional	Guidance for filling in water	Cup indication for 1 to 6 cups	10	4	5
Optional	User information	Give information to alert when water is ready	7	4	5
Optional	Indicate water temperature	Measure and indicate water temperature in a range from 50° to 100°C	7	4	5
Fixed	Automatic switch off	Reduce lag time of switch to <2 s	10	4	4
Optional	Insulate housing	Keep temperature for minimum 20 min	5	5	5
Total score				161	185
Relative performance of variant (expressed in % of total weighted score)				83%	95%

As an example, "Guidance for filling in water" is very important to the re-design process, therefore the weight of that specification is high (a scale from 0 to 10 is used here; 0 stands for not important, 10 means very important). The function fulfillment for each specification is rated with numbers from 5 to 1; whereby 5 stands for very good, 4 for good, 3 for normal, 2 for bad and 1 for very bad function fulfillment.

Multiplying the weight by the function fulfillment and summing up the achieved numbers yields a total score of the concept variant. The best variant can be selected upon that score.

According to Table 56, variant V2 is performing better than variant V1. A full evaluation of variants can only be performed when considering also other product (also non environmental) specifications, intentionally not mentioned here in this book or in Table 48. These specifications include quality-, cost-, manufacturing-, … requirements. A final decision can only be made when considering all these specifications in the evaluation as well.

4.6 Embodiment design



Once the product concept has been evaluated against the product specifications, the embodiment design can start. The realization of the identified ECODESIGN improvements is then completed.

Engineers in product development do not need help; they are used to do this as their daily business. The important issue was to find and highlight the important ECODESIGN tasks and possible ways to solve them. Going into detailed design work is not the objective of this book any more and would not add value in terms of understanding and demonstrating a systematic way of re-designing products. For the water kettle only one example of a design task during the embodiment design, i.e. the switch unit, shall be discussed.

The task is to improve the switch unit to be more sensitive for smaller volumes (e.g. ½ liter of water) and for reducing the lag time of the switch unit for switching off the water kettle once the water is boiling. The switch unit is shown in Figure 43.

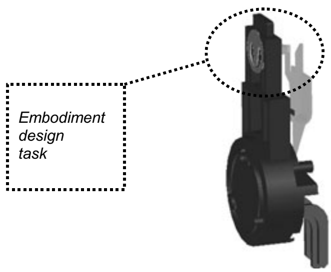


Figure 43 Detailed design of the switch unit.

A reduced lag time of the switch unit could be achieved by changing the bimetal to a more sensitive one or by redesigning the housing in a way that the currently used

bimetal is exposed better to the water temperature (improved heat transfer), which would result in switching off earlier.

Both improvements can be made easily and demonstrate how the overall environmental re-design task for the whole product can be systematically narrowed down to detailed design changes easily to understand and perform in daily design routine.

Table 57 summarizes the results of the product improvement and Figure 44 sketches an improved water kettle.

Table 57 Achieved ECODESIGN improvements.

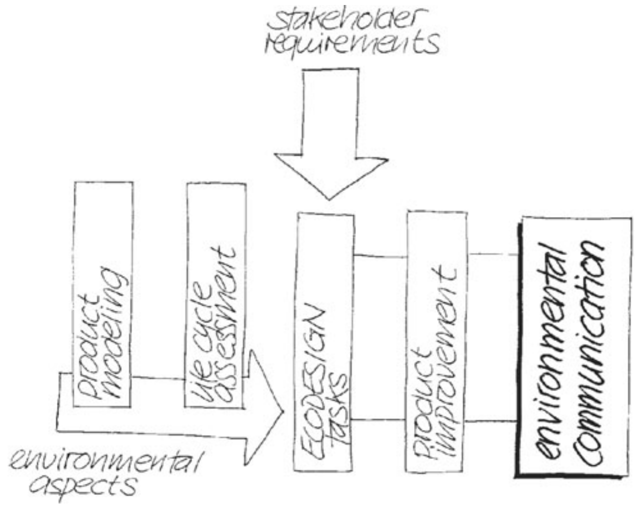
ECODESIGN improvements	*Achievements over the entire life cycle*
Installation of indication for the water temperature above a certain threshold value to avoid re-boiling.	Estimated energy saving potential of about 8.0 kWh due to avoiding re-boiling.
Redesigning the switch unit to be more sensitive due to better heat transfer between housing and bimetal.	Total energy saving of 9.0 kWh.
Providing double wall housing for better insulation – this maintains the water temperature over a longer period of time and contributes to avoiding re-boiling.	Estimated energy saving potential of about 8.0 kWh due to avoiding re-boiling.
Giving guidance for filling in water with a water gauge in cups to avoid heating more water than needed.	Estimated energy saving potential of 30.0 kWh due to filling right amount of water.
Designing a separate ground plate for easy to use and free movement of the kettle.	Better usability of product.
Recyclability of materials	Recycling rate of 70% exceeding WEEE minimum requirements.
Phasing out lead	No hazardous materials in the product according to RoHS.

Figure 44 Improved water kettle.

The design improvements from Table 57 need to be communicated to the market. Chapter 5 will answer the question “How to communicate environmental improvements to the market?” and demonstrates two possible ways to do so.

Chapter 5

ENVIRONMENTAL COMMUNICATION



The ultimate goal of ECODESIGN is to improve a product's environmental performance. However, communicating the environmental performance of the improved products (eco-products) to the market is equally important as ECODESIGN itself.

Reason and motivation for a company to develop eco-products is to increase the market share of the product, and to enhance the corporate image as caring for the environment. The newly developed eco-product would be the carrier to push the corporate business strategy in the new area of market, environment. As a result, the environmental aspects of the product now have to be communicated to the customers and relevant stakeholders. In this sense, the marketing department must be deeply involved in the communication of the environmental aspects of eco-product.

Tools for communicating environmental aspects of a product to the market, e.g., environmental labeling, self-declared environmental claims, and Environmental Product Declaration (EPD) are reviewed, and their application areas, pros and cons are discussed in this chapter. Emphasis is given to the EPD, which lists quantitative environmental information extracted from the LCA results in a format with preset data categories and data parameters. Methods for transferring LCA results to the EPD with different target audiences are discussed, and an example, EPD for the water kettle is presented.

5.1 Introduction to environmental communication

You have now completed the environmental assessment of a water kettle by performing LCA. Using the ECODESIGN approach, you have developed a new water kettle with improved environmental performance compared to its predecessor water kettle. Now what would you do next?

It is clear that the next step is to communicate environmental aspects of the newly improved water kettle to the market. This type of communication is termed environmental communication of a product. Through the environmental communication, you aim at increasing consumer's awareness of the water kettle such that market share of the water kettle may increase or at the least enhancing the image of the company. These are the very incentives for you to redesign water kettle with improved environmental performance.

Environmental communication of a product can take many different forms. They are:

- Eco-label certified by the independent third party,
- Self-declared environmental claims,
- Environmental product declarations based on LCA results.

In the case of the eco-label certification or self-declared environmental claims, most of the time LCA results are not required. For the environmental product declarations, however, LCA results of the product are required.

5.1.1 Eco-label

Eco-label or type I environmental labeling according to the ISO 14024 standard (ISO 14024, 1999) is in wide use today in many parts of the world. Ecolabeling programs that meet the requirements of the ISO standard include the Blue Angel in Germany, Nordic Swan in the Nordic countries, EU flower in the EU, Environmental Mark in Japan and Korea and Environmental Choice in Canada, among others (see section 3.2.5).

Type I environmental labeling program awards its eco-label to products that meet a set of predetermined requirements (e.g. product environmental criteria, product function characteristics, etc.). The label thus identifies products that are determined to have less stress on the environment within a particular product category. A key point here is how the environmental criteria of a product are selected and how the environmental impacts of these criteria are determined. The ISO standard on type I environmental labeling (ISO 14024, 1999) states that product should meet environmental criteria based on life cycle considerations. This means that the product must demonstrate environmental superiority over competing products that serve the same function throughout its entire life cycle.

The type I environmental labeling program is a pass-fail system; products meeting the specific values imposed by type I program's criteria can obtain the label. However, due to the selectivity principle, only 20 to 30% of the products in any product category are awarded labels. Products that cannot obtain the label, or choose not to apply, may have disadvantages in competing against products that do have the label in the same market.

Type I environmental labeling, though voluntary in nature, can exert significant impact on the market if the environmental awareness of the consumer is high. These voluntary systems may facilitate the trade of environmentally preferable products. At the same time, they have the potential to create technical barriers to trade.

5.1.2 Self-declared environmental claims

Self-declared environmental claims or type II environmental declarations according to the ISO 14021 standard are environmental claims made without independent third-party certification. Environmental claims are statements, symbols or graphics that indicate the environmental aspects of a product or service, and can be made on product or packaging labels, product literature, technical bulletins, advertising, publicity or any communication media (ISO 14021, 1999). Terms such as 'recyclable' and 'biodegradable' are examples of statements used in self-declared claims and the Mobius loop is an example of a symbol.

Twelve selected claims that represent terms commonly used in environmental claims are addressed in the standard for type II environmental declarations (ISO 14021, 1999). They are: Recyclable; Recycled Content; Reduced Resource Use; Recovered Energy; Waste Reduction; Reduced Energy Consumption; Reduced Water Consumption; Extended Life Product; Reusable and Refillable; Designed for Disassembly; Compostable; and Degradable. Specifications for these claims and qualifications for their use are provided in ISO 14021.

Environmental claims made by the company (self-declared environmental claim), however, are often difficult to verify. This can lead to marketplace confusion for the consumer. These environmental claims may be unsupported and thus counter-productive to helping consumers make informed environmental choices among products. For this reason, regulations regarding the use of environmental terms and symbols have been introduced in many parts of the world. Many of these regulations are now based on the international standard, ISO 14021. These regulations are not only applicable to domestic products but also to imported products. Hence, these ISO 14021 based regulations have the potential of being used as trade facilitators as well as barriers (Lee and Uehara, 2003).

The fundamental difference between self-declared environmental claims and type I eco-label programs is that the former are made by the claimant while the latter by the third party. Below is an example of the type II self declared environmental claims of the newly improved water kettle. It shows steps required to make the claim and then actual claim.

First, gather information on what aspects of the product were improved environmentally over the reference product. In the case of the water kettle, energy consumption of the water kettle during the product use stage was the most obvious improvement. The other improvements include the reduction of hazardous materials in the product and increase recycled material content in the packaging.

Based on these improvements, self-declared environmental claims of the improved water kettle is:

> The newly designed water kettle (new model name) is energy efficient by 7.3% (37.8 kWh/year) during the product use compared to the previous model (40.8 kWh/year). The water kettle does not contain lead or PVC. In addition, the packaging of the water kettle now contains 70% recycled material compared to 50% in previous model.

5.1.3 Environmental product declaration

Environmental product declaration (EPD) or type III environmental declarations according to the ISO standard (ISO/TR 14025, 2000) were developed to meet consumer demand for detailed information on the environmental aspects of a product. Unlike eco-label showing only a logo or self-declared claims with few text and symbols, the EPD presents environmental aspects of a product throughout its entire life cycle (LCA results) and other product related environmental information. Typical target audiences include B2B (business-to-business: suppliers to manufacturers in supply chain) or B2C (business-to-consumer: both retail level and institutional level consumers).

An EPD presents quantified information of a product's environmental loads and impacts throughout its entire life cycle stages. The information is extracted from the LCA results of the product, and arranged in an orderly manner using a standardized format. Environmental loads and impacts are cataloged according to the preset data categories and parameters which consist of two elements: data categories and data parameters belonging to the data category. Examples of preset data categories and data parameters include global warming as the data category, and CO_2 and methane (CH_4) as the data parameters.

Basic data for the EPD are the LCA data critically reviewed by an external, independent third party as stipulated in ISO 14040. The form or format of EPD is determined by a set of requirements, and the requirements are unique to each product category. The EPD should be developed aiming at a specific target audience.

In addition to the information from the LCA results, other relevant environmental information related to the product can be included in the EPD. For instance, the certification of a factory to ISO 14001, an awarded eco-label to the product, the company's environmental policy, etc. can be part of the EPD.

5.1.4 Comparison of the three environmental label types

As shown in Table 58, each type of environmental label and declaration has targeted different market segments (Lee and Uehara, 2003). While type I environmental labeling and type II self declared environmental claims aim at retail level consumers, target audiences for EPD or type III environmental declarations are business as well as retail level consumers. Furthermore, the requirement to use LCA is a unique feature of type III environmental declarations that distinguishes it from the other two types.

Consumer organization prefers type I environmental labeling because it is a third party certified program. However, small and medium enterprises (SME) often cannot afford access to type I environmental labeling programs because of costs. In addition, innovative products cannot access type I environmental labeling because there is no product category in these programs into which an innovative new product can fit (Lee and Uehara, 2003).

Industry prefers type II environmental declarations because there is no need for outside scrutiny of the product or service. In fact, manufacturers push self-declared environmental declarations as the environmental advertising tool of choice. As long as the self declared environmental claim abides by the rules stipulated in ISO 14020 and 14021, the claim is an acceptable means of communicating environmental aspects of the products to the market. In short, the claim can be a great marketing tool for industry.

Table 58 Different types of environmental labels and declarations, advantages, disadvantages and application areas (Lee and Uehara, 2003)

Item	*Type I*	*Type II*	*Type III*
Generic Name	Eco Labeling	Self-declared Environmental Claim	Environmental Product Declaration
Target Audience	Retail Consumers	Retail/industrial/ institutional consumers	Industrial/ Institutional/ Retail Consumers
Communication Method	Environmental Label	Text and Symbol	Environmental Profile Data sheet
Scope	Whole life cycle	Single aspect	Whole life cycle
Use of LCA	No	No	Yes
Advantage	Easily identified Quick decision Credibility through third party	Market oriented Flexible approach to market needs Tool for inter-business competition	Detailed data via common method Credibility via scientific quantitative data
Disadvantage	Only uses a symbol (logo) No detailed information No linkage to company's unique effort	Relatively low credibility Need to face consumers directly (no third party) Claim is about a single issue or limited	Complicated LCA analysis Insufficient back ground data Not easy to comprehend
Application area	Home use products/ simple function products/ low priced products	Products in general	Products for industrial use/ relatively complicated and high priced products/durable products

In Japan, industry prefers a modified form of self-declared environmental claims. It includes information similar to that required by EPD in the self-declared environmental claims. This modified self-declared environmental claim is often called "type 2.5" environmental declarations.

5.2 Environmental product declaration in detail

5.2.1 Who are the target audiences?

Different types of audiences require or demand different types of environmental information. There are three possible target audiences for the EPD. They include: retail level consumers, institutional level consumers, and B2B consumers along the supply chain. Below is a brief description of the nature and requirements of each target audience.

Retail level consumers

These are lay people who do not possess expert knowledge on LCA. However, they do have basic knowledge about the environmental impacts represented by impact categories such as global warming or acidification, among others.

In general, retail level consumers demand simple, and easy to understand information. However, they also want quantified, relevant and comprehensive environmental information of a product, not just an eco-label or a simple environmental claim. Therefore, the EPD of a product aimed at retail level consumers should be succinct, while conveying a simplified version of the LCA results plus additional environmental information.

Institutional consumers

These are all levels of governments, public agencies and institutions, large corporations, and super retail stores. They are big volume purchasers such that they demand much more detailed environmental information of the products they purchase than retail level consumers.

In general, institutional consumers have expertise in the environmental issues and have knowledge of LCA. Consequently, the EPD of a product for institutional consumers should include comprehensive environmental information with a detailed version of the LCA results plus additional environmental information related to the product and the manufacturing company itself.

B2B consumers in supply chain

These are suppliers of materials, components and parts of a product. The materials suppliers are, in general, big corporations; however, components and parts suppliers are typically small and medium enterprises. Demand for eco-products requires environmental information of materials, components and parts of the final product.

B2B consumers not only demand for the environmental information of materials, components and parts from their suppliers but also provide environmental information of their product to their customers. The system boundary of the LCA of the product do not span the entire life cycle but are limited to the cradle to gate, for no information can be secured once the product leaves the factory gate. Other than differences in the product system boundary, the EPD aimed at the B2B consumers are similar to that of the institutional consumers.

5.2.2 How to develop an environmental product declaration?

In developing EPD, we first define an EPD format for a particular type of audience, and then present the method for transferring the LCA results and other additional environmental information into the format. In this book, we will only deal with the institutional consumer. Basically the same procedure applies to the other types of audiences.

1) Format of an environmental product declaration

Table 59 is an EPD format suggested in this book. The format includes three main elements: product information, environmental information, and additional information. Each element includes sub elements and specifics of the sub element. The format, however, should be envisaged as an example, rather than as a template. You should develop your own EPD format based on the characteristics of a particular product as well as their target audiences.

Table 59 Suggested EPD format with main and sub elements.

Main elements	*Sub elements*	*Specifics of each sub element*
Product information	Product related information	– Product name – Model number – Product category – Product description
	Manufacturing company information	Name, postal address and contact details (toll free number, web site address) of the manufacturing company
	Product composition	Name and weight of components and materials of the product and packaging
Environmental information	Product function	Function, functional unit and reference flow
	System boundary	Use of Raw Materials, Manufacture, Distribution, Product Use and End of Life (Also show decision rule for mass inclusion and allocation method)
	Environmental profile of the product	(i) Inventory results and characterized impact results (ii) Characterized impact results per life cycle stage
Additional information		Miscellaneous environmental information not addressed in the product and environmental information

All the elements listed in Table 59 are self-explanatory except environmental profile of the product having two specifics. Environmental profile of the product based on the inventory results plus characterized impact results may take the format as shown in Table 60. Environmental profile of the product based on the characterized impact results per life cycle stage may take the format as shown in Table 61. Tables 60 and 61 only show the case of global warming for illustrative purposes. The complete table should include all the other impact categories.

Table 60 Suggested format for the presentation of inventory results plus characterized impact results of a product.

Category	*Parameter*	*Inventory value*	*Unit*	*Characterized impact value*	*Unit*
Global warming				Total	g CO_2-eq. %

Table 61 Suggested format for the presentation of characterized impact results per life cycle stage of a product.

Category	*Unit*	*Total*	*Use of raw materials*	*Manufacture*	*Distribution*	*Product use*	*End of life*
Global warming	g CO_2-eq.						

2) How to process data to make EPD?

Below is a how-to-do instruction to complete the EPD format suggested above.

Product information

List of general information related to the product, manufacturing company and product composition.

- Product related information
  Fill out relevant information next to the product name, model number, product category, and product description.
- Manufacturing company information
  Register relevant information next to the name of the manufacturing company, postal address, and contact details (toll free phone number and web address).
- Product composition
  Record components and materials used in a product and its packaging. The product composition includes weight of each component/material, and its weight fraction to the total product plus packaging.

Environmental information

List of information extracted from the LCA results of the product.

- Product function
  Register function, functional unit, and reference flow of the product.
- System boundary
  Record the system boundary of each of the five life cycle stages, i.e., Use of raw materials, Manufacture, Distribution, Product Use and End of Life. In addition, record the decision rule for mass inclusion applied and the allocation method used.
- Environmental profile of the product
  It consists of two major results from the LCA study. One is both the inventory analysis and characterized impact results and the other is the characterized impact result per life cycle stage.
  (i) Inventory results and characterized impact results

Record characterized impact values next to the following impact categories:

Global warming, acidification, eutrophication, photochemical oxidant creation, and abiotic resource depletion

For each impact category, list the inventory parameters with contributions greater than a certain percentage (e.g., 1%) of the total impact of the impact category.

If a specific product does not have one or more of the impact categories listed here, or if a specific impact category does not have more than one inventory parameter, then simply transfer the available characterized impact value and/or inventory parameter value.

(ii) Characterized impact results per life cycle stage

Record characterized impact values for each of the five life cycle stages.

Additional information

If additional environmental information related to the product such as eco-label or ISO 14001 certification of the product manufacturing facility exists, it can be recorded in the EPD format. It is also necessary to identify the practitioner who performed the LCA of the product, the critical reviewer of the LCA study, and any technical support used in making the EPD of the product.

Below is a case study how to make environmental product declaration using the LCA results of the water kettle presented in chapter 2. In fact, the LCA results of the newly improved water kettle through ECODESIGN should be used for the EPD. Communicating the environmental performance of the newly improved product should be the objective rather than that of the reference product. Furthermore, the very intention of developing an improved product is to communicate its improved environmental aspects to the market such that the newly designed product should be the one for the EPD. Since the purpose of this example, however, is to demonstrate the transfer of the LCA results of the product to the EPD, the LCA results of the reference water kettle has been used here.

The EPD shown here is intended for the institutional consumer. Note that the EPD format shown above is the basis for the EPD of the water kettle. The EPD format is four pages long such that there is a page number in the EPD.

Relevant data for the EPD format originated from the sources identified below.

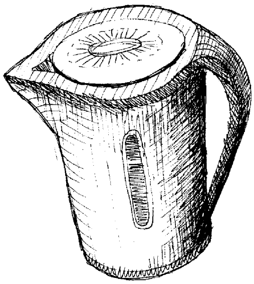
- The product composition of the water kettle described in Table 12 in chapter 2.
- The product function and system boundary information reported in the goal and scope definition results of the water kettle in section 2.3.1.
- The inventory results of the water kettle came from Table 21 in chapter 2.
- The characterized impact results of the water kettle listed in Tables 25 and 26 in chapter 2.
- The percent contribution values came from Table 28 in chapter 2. (Note that except the contribution analysis results from the global warming category, no other contribution analysis results were shown in section 2.3.4 such that you cannot import percent values of the other impact categories.)

Environmental Product Declaration (EPD)

(1) PRODUCT INFORMATION

Product related information

Product name	Water Kettle
Model number	Model A
Product category	Water kettle
Product description	The water kettle boils 1/2 liter of water by rapid boil technology. The water kettle is equipped with: Scale filter, Lid, Lid release button, Automatic switch off, Water level indicator, and Base with cord storage. The weight of the water kettle: 670 g The weight of the packaging: 200 g Total weight of water kettle with packaging is 870 g.



Manufacturing company information

Name of manufacturing company	Company S
Postal Address	Somewhere in Europe
Contact details (Phone numbers and web address)	

Product composition

Component	Material	Weight (g)	Mass (%)
Housing	PP	330.00	38
Packaging	Card board	200.00	23
Heater	Stainless steel	120.00	14
Ground plate	PP	80.00	9
Cable (PVC)	PVC	72.00	8
Cable (Cu)	Cu	48.00	6
Switch unit	PA	20.00	2
Total		870.00	100

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(2) ENVIRONMENTAL INFORMATION

Product function

Function	Heating potable water for preparing tea or coffee.
Functional Unit	Heating 0.5 liter of potable water to boiling point.
Reference flow	One water kettle of which weight is 870 g including packaging.

System boundary

Lifecycle stage	Description of the system boundary
Use of raw materials	It includes natural resources extraction from nature and production of raw and ancillary materials from the resources.
Manufacture	It includes manufacturing of parts and components in the suppliers manufacturing sites, and assembly of the water kettle at the manufacturing site of the company S.
Distribution	It includes transport from company S to major European markets. The distribution distance is approximately 3000 km within Europe by 40 ton trucks
Product Use	The amount of electricity required heating 0.5 l of water in a water kettle to prepare tea or coffee was 0.0545 kWh per use. The water kettle provides heated water for 3 times a day, 5 days a week, and 50 weeks a year over the 3 years.
End of life	It includes collection, treatment and disposal of the waste water kettle. Approximately 30% of the waste water kettles are landfilled, 20% incinerated and 50% recycled at the end of the product's life.

Decision rule for mass inclusion	All materials up to 75 % cumulative weight of the total product weight were included.
Allocation method	Economic value was used.

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Environmental profile of the product

i) Inventory results and characterized impact results

The life cycle inventory parameters in the table shown below contribute to the respective impact category with more than 1% of the total impact in that impact category.

Category	Parameter	Inventory value	Unit	Characterized impact value		Unit
Global warming				Total	39725.8	g CO_2-eq.
	CO_2	38 143.87	g			96.02 %
	CH_4	68.78	g			3.98 %
Acidification				Total	157.52	g SO_2-eq.
	SO_x	153.62	g			97.52 %
	NO_x	5.57	g			2.48 %
Eutrophication				Total	0.72	g PO_4^{3-}eq.
	NO_x	5.57	g			100.0 %
Photochemical oxidant creation				Total	2.37	g C_2H_4-eq.
	CH_4	68.78	g			17.30 %
	CO	1.33	g			1.69 %
	VOCs	4.22	g			74.26 %
	NO_x	5.57	g			6.75 %
Abiotic resource depletion				Total	37.38	g/yr
	Crude oil	615.11	g			40.80 %
	Coal	6 371.52	g			58.64 %

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ii) Characterized impact results per life cycle stages

Category	Unit	Total	Use of raw materials	Manufacture	Distribution	Product Use	End of Life
Global warming	g CO_2-eq.	39 725.81	1500.53	1037.65	241.43	37 061.70	115.50
Acidification	g SO_2 -eq.	157.52	8.66	4.05		144.70	0.11
Eutrophication	g PO_4^{3-} -eq.	0.72	0.71				0.01
Photochemical oxidant creation	g C_2H_4 -eq.	2.37	1.92	0.00	0.04	0.40	0.01
Abiotic resource depletion	g/yr	37.38	16.32	0.58	1.82	20.88	2.22

Note: No characterized impacts were calculated for toxicity and solid wastes due to lack of credible, internationally agreed characterization factors.

(3) ADDITIONAL INFORMATION

- The scale formed in the water kettle should be removed on a regular basis during the product use stage.
- The product complies with the Eco-label scheme xxx
- The LCA study and the EPD of the water kettle were made by the S company together with the Y consultant. The LCA study was verified through critical review by Z institute.
- For further information see webpage www.xxxxx.com.

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How to read the EPD environmental information?

Of the three types of information, the product information and the additional information are easy to understand. However, the environmental information deserves explanation to interpret it correctly. In the environmental information, product function, system boundary and environmental profile are listed. The product function and system boundary are mere transfer of those defined in the LCA of the product. The purpose of these two elements included in the environmental information is to delimit the EPD. In other words, the environmental declaration in the EPD is only valid within the constraints of the product function and product system boundaries defined in the environmental information section.

The environmental profile of a product is the core of the EPD. It shows two types of LCA results: inventory analysis results and characterized impact results. Since the EPD is for external use, only the mandatory part of the LCA is shown. In other words, optional elements such as normalized impact and weighted impacts are not part of the environmental profile of the product.

In order to increase the transparency of the environmental profile information, both inventory results and characterized impact results are shown first. Here inventory parameters with their values and their relative contribution to the given impact category are recorded. In addition, the characterized impact values are also recorded.

For instance, in the case of global warming impact category, inventory results of CO_2 and CH_4 and their contribution to the global warming impact category were 38 143.87 g and 68.78 g, and 96.02% and 3.98%, respectively. The global warming impact was 39 725.81 g CO_2 equivalent per water kettle. From this, contribution to global warming by the water kettle is known. Similar interpretations can be made for the other impact categories.

The other way of presenting the environmental information is to express the characterized impact results per life cycle stage. Here, no inventory results are presented. This is to highlight where the impact occurs in the life cycle stages. In the case of global warming, the product use stage is the most dominant one with the value of 37 061.70 g CO_2 equivalent. This is more than 93% of the total global warming impact of the water kettle. Thus, one knows that the product use stage is the key source of the environmental impact of the water kettle.

Negative value in the end of life stage indicates positive environmental impact. This means that environmental benefit occurs rather than adverse impact to global warming when water kettle undergoes the end of life stage. This is due to recycling of the waste water kettle. Similar interpretations can be made for the other impact categories.

5.3 Summary

Environmental communication of a product to the market is an integral part of ECODESIGN. Through the environmental communication, one can encourage the demand for eco-products. As a result, more environmentally preferable products can be sold or the image of the product and the company can be enhanced.

Environmental aspects of the newly redesigned product should be better than those of the previous model or competitors' products. By highlighting the difference or improvements over the other products, one can distinguish the product from the others. It is thus critically important to have a good product in the first place.

All the communication including environmental annotations should be accurate, non-misleading and reliable. Hence, strict adherence to the legal regulations as well as international standards is prerequisite to any environmental communication. Since there are different types of target audiences, retail, institutional, and B2B, different types of environmental communication means should be utilized.

In the case of the retail level consumer, the EPD must be designed to be simple. If not, no retail level consumer will be able to understand the information in the EPD. In the case of the B2B consumers, the EPD format suggested here can be applied by modifying system boundaries, for the system boundary of the products manufactured by the B2B consumers typically span from cradle to gate, i.e., from resources extraction (cradle) to materials production, and components or parts manufacturing of the manufacturing factory's exit gate.

It is now evident that the level of detail of the environmental information is critical in the EPD. If it is too complicated, very few will understand the information contained in the EPD. If it is too simple, there will be no need for the EPD. The EPD shown in this chapter aimed at the institutional consumer such as government procurement office and big corporation's purchasing department. It was a basic premise that they have experts who are capable of choosing the environmentally preferable product by reading the information disclosed in the EPD.

Chapter 6

CONCLUSION

ECODESIGN has the potential to optimize the performance of products by reducing material and energy input over the entire product life cycle stages. ECODESIGN opens the focus on all life cycle stages of product system and other aspects and makes therefore other field of actions visible. Results of a systematic ECODESIGN process are innovative solutions that are characterized by lower life cycle costs. Furthermore, the ECODESIGN process leads to higher legitimacy of the product itself and the company which produces this product. Therefore, ECODESIGN will be a key success factor for the company.

A better understanding of all life cycle stages at the beginning of the product developing process is of central importance because most of the relevant planning and decision making processes will be made at this early planning stage.

A good product concept which is developed in the early product planning stages will simplify later developing processes and will lead to an optimized product design.

This book provides the necessary information and recommendations to implement ECODESIGN systematically at the own enterprise. Figure 45 summarizes all planning steps explained in this book in an overview.

The ECODESIGN process started with the modeling task of the whole product system. Environmental parameters and life cycle stage information were defined as well as the composition of the reference product to be redesigned.

In the second task, environmental aspects of the product were assessed by using the method of Life Cycle Assessment (LCA). Significant environmental aspects, key environmental issues and environmental profile of the product are some of the major results from this task.

The third task focused on defining redesign tasks. It included sub elements such as Environmental Quality Function Deployment (EQFD), Environmental Benchmarking (EBM), the ECODESIGN PILOT's Assistant as well as a checklist based ECODESIGN PILOT. If LCA results are not available, only the results from the first task and the ECODESIGN PILOT's Assistant can be used.

The fourth task generates product specifications. Sub elements in this task are product specifications, functional structure, creativity sessions, product concept and embodiment design.

The last task dealt with the effective communication of an environmentally improved product to the market. A specific focus was given to the development of an Environmental Product Declaration (EPD). However, other communications means

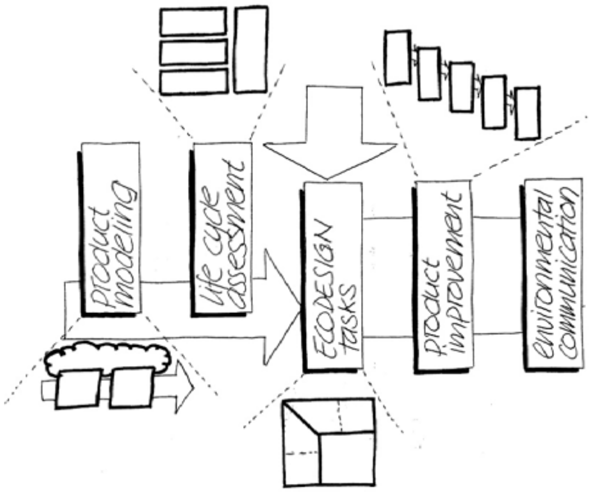

Figure 45 Overview of the ECODESIGN process.

such as eco-label, self-declared environmental claims are important options for the environmental communication.

Systematic twelve steps for implementing ECODESIGN in practice was given in Table 1 and those steps shall be recommended.

One of the central ideas of the ECODESIGN process described here is the systematic integration of significant environmental aspects and stakeholder requirements which leads to an integrative design approach as well as the fact that the results from ECODESIGN has to be communicated to the customers.

ECODESIGN is a process that integrates environmental considerations into the existing product development process of an enterprise. The ECODESIGN process should be integrated in the already existing planning and decision-making processes, e.g. process management of an enterprise on strategic and operational level. All these processes are implemented to achieve continuous improvement of the products as well as continuous learning within the enterprise. The result of implementing ECODESIGN should be an innovative and marketable eco-product with improved environmental performance.

All in all ECODESIGN is a challenge. The authors wish you success and good progress with implementing ECODESIGN.

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